Copy 91

VOYAGER

SPACECRAFT Phase B, Task D

FINAL REPORT

OCTOBER 1967

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER

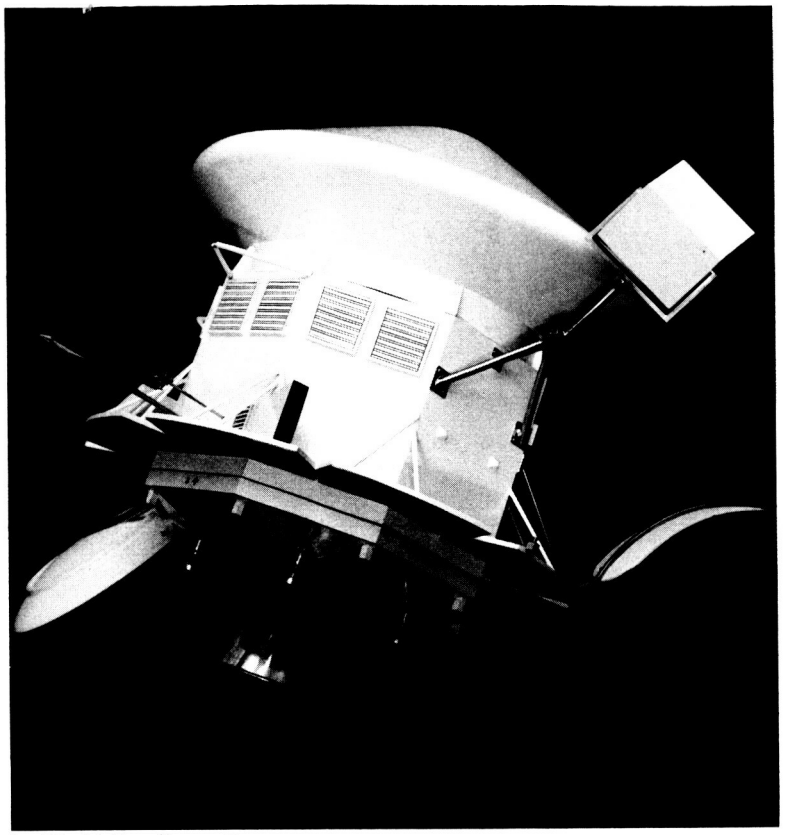
Huntsville, Alabama

Voyager Operations
Space Vehicles Division

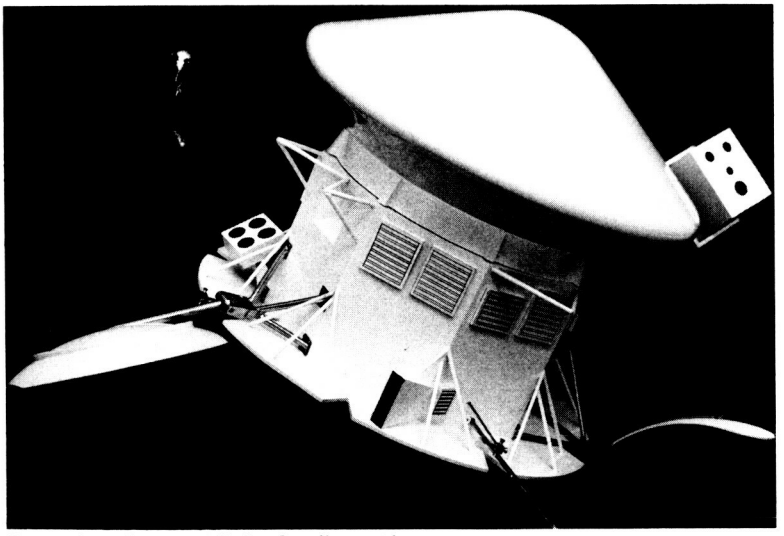
TRW SYSTEMS GROUP

One Space Park, Redondo Beach, California

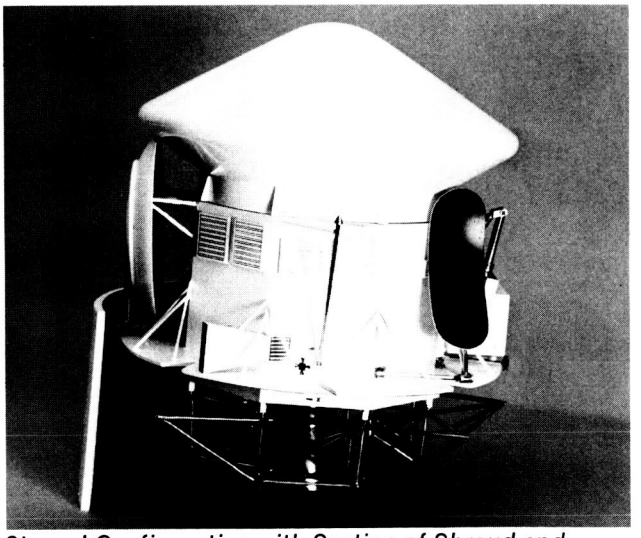
MODEL OF
TRW
RECOMMENDED
VOYAGER
SPACECRAFT



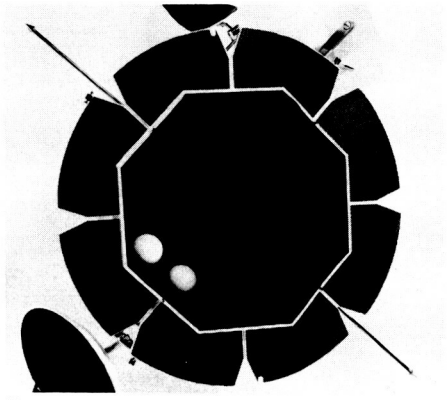
In-Flight Configuration



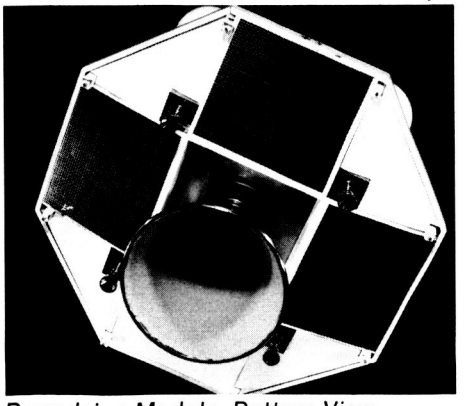
Opposite View In-Flight Configuration



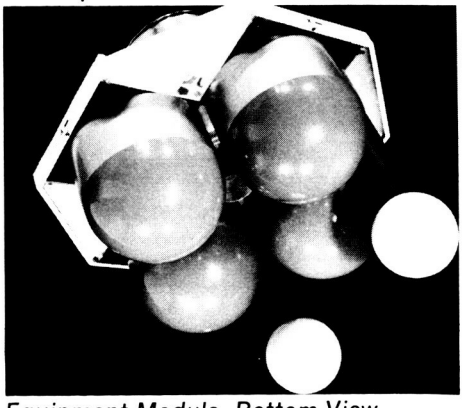
Stowed Configuration with Section of Shroud and Planetary Vehicle Adapter



Propulsion Module, Top View



Propulsion Module, Bottom View



Equipment Module, Bottom View

VOYAGER

SPACECRAFT Phase B, Task D

FINAL REPORT

Volume 9. Engineering Study Task: ETO Decontamination

OCTOBER 1967

Prepared for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

TRW
SYSTEMS GROUP

Voyager Operations
Space Vehicles Division

One Space Park, Redondo Beach, California

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

TABLES (Continued)

TABLES (Continued)

1. INTRODUCTION

The Martian planetary quarantine requirement for the Voyager program has led to the establishment of decontamination procedures based on the use of ethylene oxide-Freon 12 gas (ETO) as a biocidal agent. Effects of an ETO decontamination requirement have been evaluated, with emphasis on decontamination requirements from the biological viewpoint, spacecraft design variables, determination of a contamination control plan, selection of qualified materials and components for ETO exposure, the design and operational needs of specialized facilities and equipment, and the impact of a contamination control effort on overall program schedules. These collected data have been reduced to aid in defining the cumulative effect in terms of costs and implementation.

The Voyager contamination control plan (initially prepared during Task B) has been updated as a result of the study (Section 6). It specifies contamination control and decontamination operations from piece part fabrication through launch. Monitoring, test, and personnel training programs are also described.

In approaching the overall problem, a literature search disclosed not only the history of ethylene oxide as an insecticide and bactericide but also its use and effects on several classes of materials. In many cases, current methods of application did not match the stringent requirements that were set up for Voyager, thereby pinpointing areas needing further study and laboratory work. Because the flammable and explosive characteristics of ethylene oxide were well documented, a safety plan was drawn up for the storage, handling, application, and disposal of the ETO mixture.

To aid in establishing standards for materials and components testing, an ETO qualification test specification was prepared (Appendix B). The study also produced tentative materials and components lists for Voyager subsystems and a collection of ETO compatibility data. Subsystem designs were reviewed against ETO compatibility data; some problem areas were identified, and solutions are suggested.

Facility requirements for manufacturing, testing, decontamination, and launch site activities were developed in detail. Functional and design requirements for ETO chambers, a mobile ETO unit, and an aseptic cooling unit are presented. A procurement specification for ETO chambers is also outlined (Section 9).

The cumulative effects of ETO decontamination on the overall Voyager program were developed in terms of engineering requirements, launch sequence variations, facility modifications, and scheduled milestones. The impacts are discussed here and are reflected in the implementation plan (Volume 8).

2. SUMMARY OF STUDY

The major results of the ETO decontamination study are focused in four areas: materials and components selection for compatibility with ETO, facility requirements, equipment requirements, and program schedule effects. A summary of the results, including conclusions, problem areas, and approaches to solution are discussed in the following sections.

2.1 MATERIALS AND COMPONENTS

An examination of decontamination requirements showed that the major application of ETO was for terminal decontamination at the launch site of the Voyager spacecraft and encapsulated lander within the planetary vehicle compartment. It was also to be applied as a flight acceptance test at the unit and system level. Qualification of materials and components to six ETO cycles was considered suitable to demonstrate their ability to satisfactorily undergo the flight hardware ETO environment. Using this qualification requirement as a basis for evaluating compatibility data obtained through the literature, it has been concluded that there should be no serious problems in material and component selection. There is a deficiency of ETO-material and component compatibility data, but the data that does exist indicate little or no degradation of most items by ETO. In most cases of incompatible or marginal items, compatible alternates exist. In other cases, the sensitive component will be in units designed to be sealed, and thus will not contact the ETO during terminal decontamination.

Sensitive areas have been identified as follows:

Subsystem	Materials and Components of Concern
Propulsion	Propellants
	Lubricants
	Wire insulation
	Elastomers
Electrical	Conductive adhesive
	Capacitors
	Wire insulation
	Magnetic tape
	Photographic film
	Marking materials
Structures	Adhesives

The propellants, magnetic tape, and photographic film must be isolated from the ETO environment. This is not a problem because the units utilizing these items are designed to be sealed. The other areas listed represent those in which sensitive materials and components have been demonstrated, and care must therefore be exercised in making selections.

Many of the materials and components expected to be used on Voyager have not yet been tested for ETO compatibility. Their compatibility must be established prior to their inclusion in the final design. This will entail a large-scale test program. Tests on materials and components should not only include determination of degradation immediately following ETO decontamination, but also of residual effects.

2.2 FACILITIES

Major facility requirements identified in the study are clean rooms, ETO facilities for evaluation and test, and a terminal decontamination facility.

Class 10,000 clean rooms appear most suitable for all operations from unit assembly through terminal decontamination, in order to control biological contamination to levels most conducive to effective ETO decontamination. The need for clean rooms is not specific only for the ETO requirements; it is shared by particulate contamination control requirements. The impact of the clean room requirement, particularly for test areas such as the anechoic chamber and the vibration test facilities, must be further investigated to determine if class 10,000 clean room design appears feasible, and the controls which must be instituted to maintain this class of cleanliness in these test areas.

Requirements on facilities for ETO test and decontamination include an ETO storage and distribution area, and a gas neutralization and ventilization system. The supply and disposal of the ETO sterilant gas requires more investigation. Most of the problems related to supply will be worked out jointly with the vendors of the sterilant gas. The disposal of the ETO mixture poses a two-fold problem, since there

is a biological as well as a flammability hazard. The approach to the solution of these problems will be an evaluation of several disposal methods in terms of convenience, effectiveness and safety. At the present, chemical reaction to provide readily disposable, harmless products appear the best method. Other methods which can be considered are: 1) atmospheric exhaust after dilution with air, 2) solution in domestic drain water, and 3) catalytic or thermal decomposition.

2.3 EQUIPMENT

Equipment needed to perform ETO decontamination tasks include microbiological monitoring equipment, cleaning equipment, ETO chambers for test and decontamination, and ETO and aseptic gas supply units for terminal decontamination and ground cooling.

Microbiological monitoring equipment requirements include ultrasonic scrubbing tanks for whole part sampling, and air and surface samplers. Electrostatic air samplers and a vacuum probe surface sampler appear useful.

Ultrasonic tanks and vapor degreasers are needed for cleaning small items, and vacuum cleaners are required for large assemblies. Studies of washing techniques show that ultrasonic scrubbing followed by vapor degreasing is very effective in removing microbiological contamination. Ultrasonic scrubbing alone is slightly less effective. Vapor degreasing alone is not very efficient.

Equipment to provide appropriate ethylene oxide exposures for evaluation and test may be provided by means of careful selection and specification of the exposure equipment. Each of these areas have requirements which are common, as established by the basic ETO exposure methodology. In addition, the unique operation and functional requirements of each area must be considered. Additional investigations are required to determine potential use of existing thermal vacuum chambers for the performance of system ETO flight acceptance test.

It has been established that most of the existing equipment for ETO exposure have certain inherent deficiencies, primarily in the areas

of instrumentation and control functions. It is therefore essential that suitable procurement specifications be developed, in conjunction with proposed manufacturers, in order to satisfy the necessarily stringent requirements of the Voyager program. The most salient apparent problems lie in the measurement of ethylene oxide concentration and the measurement of relative humidity within the chambers. Ethylene oxide concentration can be conveniently measured with existing instrumentation when it is properly applied. The measurement and control of relative humidity poses a more difficult problem in that most primary humidity sensors are adversely affected by the presence of ETO. The use of gas chromatography or nondispersive infrared appear the most feasible methods.

Principal terminal decontamination equipment include a mobile ETO unit and an aseptic cooling unit. Requirements for the units include liquid ETO and sterile nitrogen supply; ETO vaporization, temperature conditioning and humidification unit; real-time display; permanent recording of parameters; and mobility.

Requirements for the planetary vehicle compartment of the flight shroud to render it suitable for terminal decontamination have been determined to be the following:

- Inlet and exit ports for connections to the portable equipment
- Sealed one-way ports for ETO sampling and contamination monitoring
- Provisions for uniform distribution of ETO throughout the interior
- One-way aseptic pressure relief and atmospheric vent valves
- A smooth exterior surface to minimized pockets of contamination and to aid in final surface cleaning prior to launch.

More detailed investigation into terminal ETO decontamination procedures is necessary to determine the effects on the planetary vehicle

compartment detail design. This investigation will aid in establishing firm requirements for the number, size, and location of ethylene oxide and purge gas inlets, outlets, and monitoring ports. The investigation would also include an examination of feasibility and impact on PVC design of vacuum pumping to aid in the ETO cycle. The amount of time which may be saved by accomplishing this, and the additional confidence which may be gained in removing all ethylene oxide gas from the interiors of the spacecraft, are considerations for adopting this method.

2.4 SCHEDULE EFFECTS

The major impacts of decontamination on the Voyager spacecraft project are due to the need for design, construction, and qualification of specialized facilities and equipment, and the increase in manpower required to perform such contamination control tasks as developing and following contamination control procedures, participation in training programs, performing ETO qualification and acceptance testing, data collecting and reporting, and conducting terminal decontamination. The effects of these are to increase test and launch operations schedules, and to superimpose contamination control tasks on the master spacecraft schedule.

Possible serious contingencies arising from malfunctions of spacecraft systems, and the possibility that an ETO decontamination cycle may have to be repeated, should not be overlooked in planning the master spacecraft schedule.

Additional methods for maintaining the spacecraft in a clean condition, and for daily cleaning operations, will require more investigation. If the frequency of spacecraft cleaning can be reduced, improvements in manpower allocations and overall schedule can be foreseen.

The method of cooling the proposed capsule RTG isotopes and the procedures utilized to load the isotopes, as they affect spacecraft interfaces, should be investigated in terms of launch site decontamination operations and schedule implications.

3. STUDY APPROACH

The initial phase of the study involved the updating of the Voyager biological contamination control plan (prepared during Task B). This was then used as a basis to determine materials and components suitability, facility and equipment requirements, and program schedule effects (Figure 3-1). The following tasks were performed in updating the plan:

- Determine the biological and procedural requirements for ETO decontamination of the spacecraft. This involved investigating the basic parameters for ETO decontamination, and then examining the Voyager spacecraft configuration to determine those operations needed to satisfy spacecraft decontamination requisites. Consideration was given to the influence of the spacecraft geometry on the effectiveness of ETO decontamination, and the need for special decontamination of subsystems which could produce viable efflux from internal surfaces during the mission.

- Determine the tests at the qualification and flight acceptance levels required to assure spacecraft compatibility with ETO. This involved examining the relationships between the ETO environment and the flight hardware, and then determining the exposure parameters needed to verify the suitability of the design for ETO decontamination operations.

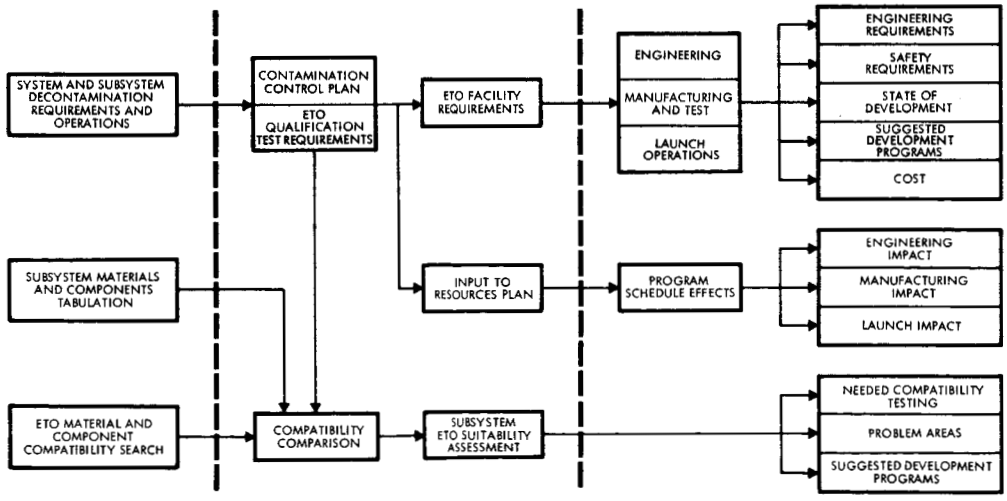


Figure 3-1

THE ETO TASK STUDY APPROACH involved updating the Voyager Biological Contamination Control Plan, then using it as a basis to determine materials and components suitability, facility and equipment requirements, and program schedule effects.

3.1 MATERIAL AND COMPONENTS

Criteria for judging the ability of the spacecraft to satisfactorily withstand the ETO environment were incorporated in an ETO qualification and acceptance test specification. The qualification test conditions formed the basis for evaluating the effects of ETO decontamination on materials and components and therefore their suitability for use in the spacecraft.

A tentative list of materials and components was prepared for each subsystem, based on performance specifications and packaging requirements. TRW-preferred materials and components lists prepared for other programs were used to select parts to meet the performance and packaging requirements.

A literature search was used to gather data on the compatibility of ETO with materials and components. This included comprehensive review of ETO effects on material and components published by TRW in June 1966, data published in the literature in the last year, and data obtained as part of the TRW Lunar Module descent engine demonstration program.

The accumulated compatibility data were compared with subsystem materials and components requirements and qualification test criteria. It then became possible to identify areas where additional compatibility information was needed. Assessment was made of each subsystem for ETO exposure, influence of the material use on its suitability, and the possibility of substituting incompatible items with compatible ones.

3.2 FACILITIES AND EQUIPMENT

Specification of facility and equipment needs was based on the operations needed to satisfy spacecraft decontamination requisites, and the tests at the qualification and flight acceptance levels required to assure spacecraft compatibility with ETO. This included defining engineering requirements, type, quantity, size, and location of decontamination chambers and equipment required for ETO decontamination of units and the spacecraft, and for performing type approval and flight acceptance tests; defining safety requirements relative to the handling of ETO, venting of chambers, etc; investigating microbiological and

particulate assay equipment; and determining the feasibility of using the shroud planetary vehicle compartment (PVC) as a decontamination envelope for terminal surface decontamination of the flight vehicle. Functional and design requirements were prepared on equipment that must be developed. Additional areas needing investigation were assessed.

3.3 SCHEDULE EFFECTS

ETO operations affecting the overall spacecraft program schedule included problems associated with materials and components selection, need for design, construction, and qualification of specialized facilities and equipment, subsystems requiring special decontamination treatments, and the development, manufacturing, test, and launch operations associated with ETO decontamination. Schedules were made for the performance of these tasks. Their impacts on the master Voyager schedule at the engineering, manufacturing, and launch levels were assessed. Lead times needed on some schedules were determined, as well as the identification of those tasks that have to be conducted simultaneously and those tasks that have to be performed serially within other elements of the master schedule.

4. BACKGROUND ON ETO DECONTAMINATION

ETO decontamination refers to surface sterilization of items inside a chamber with a gas mixture whose biologically active ingredient is ethylene oxide. The chemical formula for ethylene oxide is

$$H_2C\!-\!CH_2 \quad (O)$$

It boils at 53 to 54°F, and thus is a gas at room temperature, but is easily liquified. The gas has a faint, sweetish smell. The smallest quantity detectable by odor is about 700 parts/million. It is freely diffusible and rapidly penetrates paper, fabric, and many plastics. It is infinitely soluble in water and alcohol, and is also soluble in most organic solvents, oils, many elastomers and some plastics. Under the proper conditions, ethylene oxide is very reactive. It is widely used as an intermediate in chemical synthesis. It is extremely flammable, and its vapors form explosive mixtures in air in all proportions from 3 to 80 percent by volume. It can be rendered nonflammable by diluting with an inert gas to 12 percent by weight of the mixture (References 1, 2).*

Ethylene oxide was first described in 1859 by the French chemist Charles A. Wurtz. Its lethal properties were first clearly demonstrated around 1924 when, during evaluation of it as an anesthetic, fairly low concentrations proved fatal to experimental animals. (Reference 3) These properties were first utilized in 1928 when Cotton and Roark (Reference 4) found ethylene oxide to be a powerful insecticide, active against such pests as clothes moths, carpet beetles, meal worms, grain beetles, and rice weevils. Concentrations ranging from 3.2 to 32 milligrams per liter were sufficient to kill a variety of pests. The first reference to ethylene oxide as a bactericide was made in 1929, but most of its use until recent times had been as an insecticide.

Ethylene oxide is also toxic to humans. The maximum allowable concentration for an 8-hour exposure has been listed both as 50 and 100 parts/million. Usual symptoms of ethylene oxide toxication are irritation of the mucous membranes, nausea, vomiting, and headache. In rare instances, more serious illness and death have been reported.

---

*References are listed in Bibliography, Section 4.3.

Ethylene oxide also causes skin blisters when in prolonged contact, such as from gloves, shoes, and clothing that have been saturated with the gas.

4.1 BIOLOGICAL REQUIREMENTS

The first serious work to define the exact conditions for sterilization with ethylene oxide was reported by Phillips and Kaye in 1949. (References 3, 5, 6). They showed that effectiveness of the gas was dependent upon concentration, temperature, relative humidity, and bacterial population (Tables 4-1, 4-2 and 4-3).

Table 4-1. Time to Kill B. globigii spores (On Cotton Cloth) Depends on Temperature and Ethylene Oxide Concentration

Concentration of Ethylene Oxide		Exposure Time (hours)								Time for 90% kill (1/k) (hours)
ml/liter	mg/liter	1	1	2	4	6	8	10	24	
Temperature: 37°C										
0.025	22.1			+ + +	+ +	+	0	0	0	1.7
0.05	44.2			+ +	+	0	0	0	0	0.9
0.1	88.4		+ + +	+	+	0	0	0	0	0.6
0.5	442	+	0	0	0	0			0	0.2
1.0	884	0	0	0	0	0			0	<0.1
Room Temperature: 25°C										
0.025	22.1			+ + +	+ + +	+ + +	+ + +	+ + +	+	7.2
0.05	44.2			+ + +	+ + +	+ +	+ +	+	0	3.3
0.1	88.4			+ +	+ +	+	+	0	0	1.6
0.5	442	+ + +	+ +	+	0	0			0	0.5
1.0	884	+ + +	+ +	0	0	0			0	0.35
Temperature: 5°C										
		24 hours	48 hours	72 hours						
0.025	22.1	+ + +	+ + +	+ + +						>36
0.05	44.2	+ + +	+ + +	+ + +						31.2
0.1	88.4	+ + +	+ +	+						17.5
0.5	442	0	0	0						<5
1.0	884	0	0	0						<5

Table 4-2. Time of Exposure to Ethylene Oxide Vapor Required for the Sterilization at Room Temperature of Cloth Patches Contaminated with Various Organisms

Test Organisms on Patches	Concentration of Ethylene Oxide	
	0.05 ml per liter (hours)	0.10 ml per liter (hours)
Bacillus globigii (spores)	Between 10 and 24	10
Bacillus globigii (vegetative)	6	5*
Staphylococcus aureus	6*	6
Mycobacterium phlei	over 6*	6
Gaffkya tetragena	6*	4*
Serratia marcescens	4	3
Eberthella typhosa	2	2
Klebsiella pneumonia	2	2
Escherichia coli	2	2

*Values somewhat uncertain

Table 4-3. Effect of Relative Humidity Upon the Sterilizing Action of Ethylene Oxide upon Spores of B. globigii Affixed to Cotton Cloth

Ethylene Oxide Concentration (mg per liter)	Rate of Sterilization (time for 90 per cent kill (1/k)) (minutes)			
	25 C		37 C	
	30% RH	Saturated	16% RH	Saturated
22	324	700	108	240
88	96	210	42	108
442	20	43	10	20

The gas is more than 10 times as active at a relative humidity of 30 percent as it is at a relative humidity of 99 percent. On the other hand, extremely dry conditions result in marked decrease in activity of the gas as well. The gas is incapable of sterilizing spores which have previously been desiccated by exposure to vacuum. Prolonged rehydration of the spores is necessary to again render them susceptible to ethylene oxide (Reference 8). Hoffman measured death rates of Bacillus subtilis spores on filter paper in 120 milligrams ethylene oxide per liter at relative humidities from 1 to 98 percent at room temperature (Reference 7). He found that for relative humidities of 33, 53, 75, and 98 percent, straight-line death rates were obtained (Figure 4-1). The D values* at these humidities were 0.8, 1.3, 2.1, and 1.9 hours, respectively. For relative humidities below 33 percent, death rates were not linear (Figure 4-2); 99.9 percent of the spores were killed at these low relative humidities, but sterility was not attained even after an ethylene oxide exposure of 3 days.

While 33 percent relative humidity is optimum for porous surfaces such as cloth and filter paper, a higher humidity, ~40 percent, is best to sterilize impervious surfaces such as glass and metals (References 8, 9, 10).

When sterilization is conducted at room temperature with 10 percent ethylene oxide, it is usually possible to sterilize complex or heavily contaminated articles in 20 to 24 hours, and relatively clean or simple articles in 6 to 8 hours; with 20 percent ethylene oxide, 8 to 12 hours has usually been found sufficient for complex articles, and 2 to 4 hours for more simple items. Although the activity of ethylene oxide increases with increase in concentration, the chemical is flammable in concentrations above 12 percent in an inert diluent. The temperature coefficient of the gas varies from 1.8 to 3.1 depending on the concentration; i.e., death rate is increased by a factor of 1.8 to 3.1 for each ten centigrade degree increase in temperature (Table 4-4) (Reference 7).

*Time to kill 90 percent of a bacterial population.

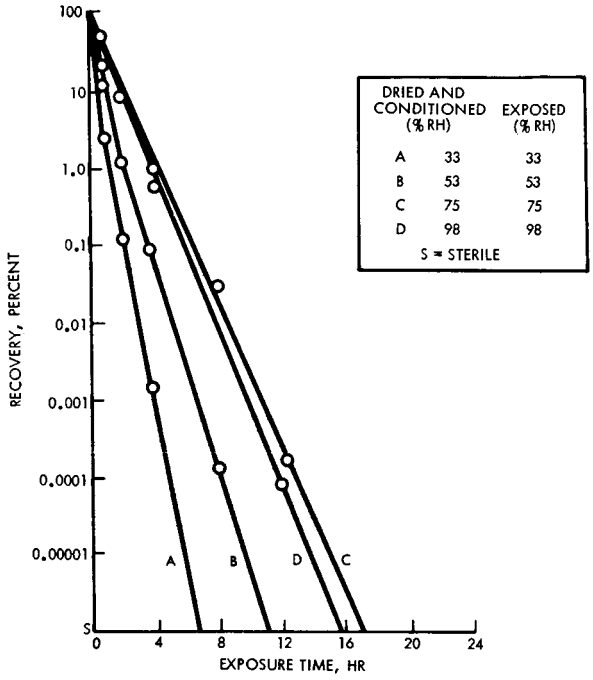


Figure 4-1

B. subtilis SPORES ON COTTON PATCHES EXPOSED TO ETHYLENE OXIDE (120 mg/L) AT 25°C, are destroyed fastest at 33% relative humidity.

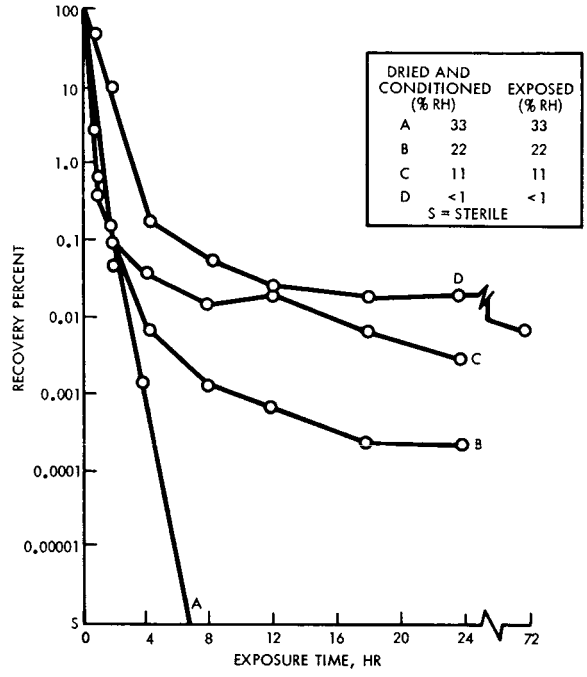


Figure 4-2

B. subtilis SPORES ON COTTON PATCHES EXPOSED TO ETHYLENE OXIDE (120 mg/L) AT 25°C, 22% or lower relative humidity, are not killed in 24 hours.

Table 4-4. Temperature Coefficients (Q_{10}) of Ethylene Oxide Varies Both as a Function of Concentration and Temperature

Investigator	Concentration (mg/L)	Temperature Range (°C)	Q_{10}
Phillips	22- 884	5-37	2.7
Ernst	440	20-40	3.1
		40-55	1.8
	880	20-35	2.5
		35-55	1.8
	1500	20-55	1.8

Effectiveness of ethylene oxide is dependent not only upon the number of viable organisms present, but also on whether or not the organisms are present in a protective medium. It has been shown that the probability of the gas sterilizing an object containing a large inoculum of spores deposited from a salt solution or covered by corrosion products is much lower than for an object bearing unprotected cells (References 11, 12). In most cases of bacteria embedded in crystals, the object is not sterilized. Abbott, et al., showed that contaminated Rochelle salt crystals could not be sterilized by a 4-day exposure to ethylene oxide (Reference 13). Other investigators likewise demonstrated the inability of the gas to sterilize contaminated glucose, calcium carbonate, sodium chloride, and glycine (References 14, 15). Inability to sterilize embedded microorganisms can be explained as either failure of ethylene oxide to permeate these materials or reaction of the gas with the materials, resulting in its consumption and unavailability for sterilization.

Phillips tested the sterilizing ability of ethylene oxide on bacterial spores suspended in oil and water (Reference 7). His studies showed that the gas would diffuse through these media to kill the microorganisms, but the time to sterilize was a function of depth. In a 24-hour exposure period using 450 milligrams ethylene oxide per liter, olive oil was sterilized to a depth of 1 centimeter and water to a depth of 2 centimeters. As depth increased, less and less kill was obtained (Table 4-5).

Table 4-5. Percent of Kill of B. subtilis var. niger Spores in Olive Oil and Water Exposed to Ethylene Oxide (450 mg/L, 24 hours, 25°C) is Inversely Proportional to Depth

Liquid		Percent Kill	
Depth, cm	Volume, cc	Olive Oil	Water
0.8	1	100	100
1.8	2-1/2	98	100
3.5	5	91	88
6.8	10	57	55

Ethylene oxide will penetrate some plastic films to sterilize objects enclosed therein. These plastics include polyethylene, polyvinyl chloride, and cellulose acetate. On the other hand, plastics such as polyethylene terephthalate (Mylar) and cellophane are not permeable to the gas (Reference 16). This factor must be considered in spacecraft sterilization because spacecrafts are usually almost completely wrapped in aluminized Mylar. Voyager will have 70 layers on most of its exterior. In order to decontaminate all surfaces, the ethylene oxide will have to diffuse between the layers since it cannot permeate through them. In studies by Willard and Alexander of sterilization by diffusion through 100 layers of aluminized mylar on a simulated thermal control compartment, it was found that the process failed in one of three tests using an 11-hour exposure period (Reference 17). The tests utilized 28 filter strips containing 10^6 Bacillus subtilis spore each, placed on the top, bottom and sides of the first, 25th, 50th, 75th, and 99th layers (Table 4-6, Figures 4-3 and 4-4). The potential problem of decontaminating layers of Mylar can be resolved by using reduced pressure between the layers to facilitate diffusion of ethylene oxide, increasing the exposure time, or reducing the microbial load to be killed.

As stated previously, ethylene oxide is flammable. To render it nonflammable, it is usually mixed with an inert diluent such as carbon dioxide, nitrogen, or Freons (chlorofluoro derivatives of methane). These diluents have no biological significance nor interfere with the sterilizing ability of ethylene oxide as long as its concentration is maintained at a high enough level for sterilization to occur in a practical amount of time. For this study, 12 percent ethylene oxide in Freon 12* is considered the mixture of choice. This mixture contains about 500 milligrams ethylene oxide per liter at atmospheric pressure. It is referred to as ETO in this report. A further discussion of the mixture is presented in the next section.

Recent studies have uncovered diluents which also amplify the sterilizing action of ethylene oxide. The Russians have reported synergism of methyl bromide and ethylene oxide, although workers in

*Dichlorodifluoromethane.

Table 4-6. In Two Out of Three Tests, ETO Sterilized Thermally Controlled Compartment, Containing 100 Aluminized Mylar Layers, in 11 Hours at Ambient Pressure, 25°C

Spore Strip			Viability after 14 days incubation at 37°C		
Side*	Sheet No.	Position from bottom of box (inches)	Test I	Test II	Test III
B(R)	1		negative	negative	negative
B(R)	50		negative	negative	negative
B(R)	75		negative	negative	negative
B(R)	99		negative	negative	negative
T	1		negative	negative	negative
T	25		negative	negative	negative
T	50		negative	negative	negative
T	75		negative	negative	negative
T	99		negative	negative	negative
R	1	12	growth in 72 hours (anaerobic)	negative	negative
R	25	12	negative	negative	negative
R	25	6	negative	negative	negative
R	50	6	negative	negative	negative
R	75	12	negative	negative	negative
R	99	6	negative	negative	negative
L	1	0	negative	negative	negative
L	1	4	growth in 72 hours (anaerobic)	negative	negative
L	1	12	negative	negative	negative
L	25	4	positive	negative	negative
L	25	0	negative	negative	negative
L	50	0	negative	negative	negative
L	50	12	negative	negative	negative
L	75	4	negative	negative	negative
L	75	0	negative	negative	negative
L	99	0	negative	negative	negative
L	99	12	growth in 72 hours (anaerobic)	negative	negative
Inside box, right side			negative	negative	negative
Inside box, left side			negative	negative	negative
Positive control			positive	positive	positive
Negative control, 1			negative	negative	negative
2			negative	negative	negative
Media control			negative	negative	negative

*B – bottom
T – top
R – right side
L – left side

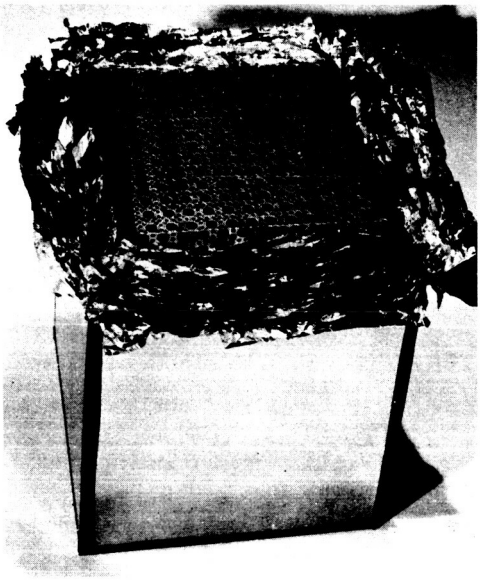
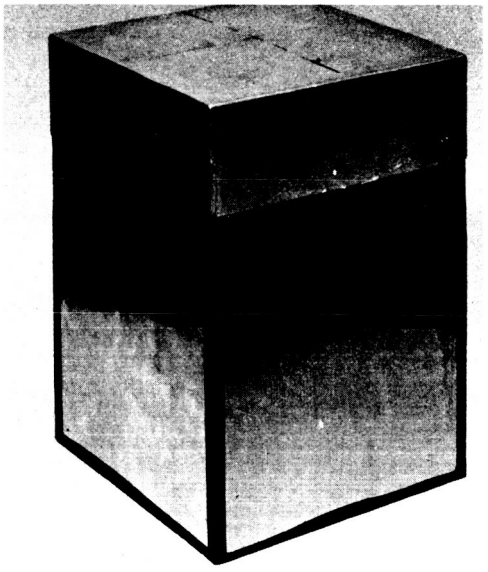


Figure 4-3
THERMALLY CONTROLLED COMPARTMENT MOCKUP for testing ETO penetration consisted of an aluminized mylar lined box inside outer box. In this photo top sheets of aluminized mylar removed.



THERMALLY CONTROLLED COMPARTMENT MOCKUP, finished double box.

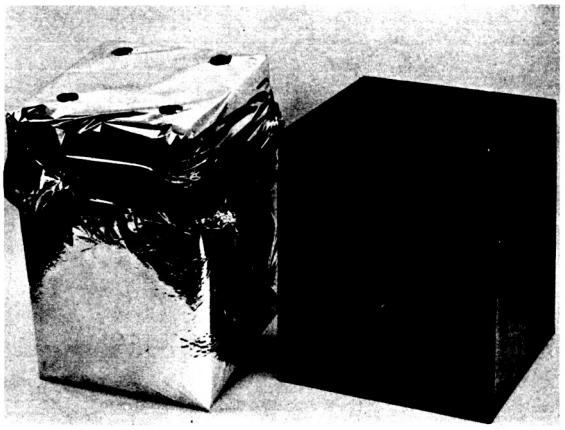


Figure 4-4
THERMALLY CONTROLLED COMPARTMENT MOCKUP, showing inner box lined with aluminized mylar.

this country have experienced difficulty in confirming this phenomenon (Reference 18). Kaye has reported synergism of ethylene oxide and methyl formate (Reference 19). He was able to sterilize objects in 10 minutes with 33 percent w/w ethylene oxide in methyl formate. The rapidity with which sterility can be achieved with this mixture warrants a consideration of investigating it for some spacecraft uses.

4.2 PROCEDURAL REQUIREMENTS

It is assumed that terminal ETO decontamination is to be applied to the Voyager spacecraft and encapsulated lander within the PVC of the shroud. Positive proof of decontamination cannot be made because the spacecraft cannot be tested without recontaminating it. Certification must be based on adherence to a set of proven procedures which are expected to produce a decontaminated item, with tests conducted on representative samples. The spacecraft can thus be certified as decontaminated in the sense that there is a certain low probability of viable surface contamination. That probability can be made as low as desired within the capabilities of the prescribed procedures. From the previous discussion of factors influencing the effectiveness of ETO decontamination, it is seen that the procedures for decontamination must include:

- Minimizing the surface biological load
- Controlling the ethylene oxide concentration. It is expected that terminal decontamination of the spacecraft will be conducted at ambient pressure. This simplifies the construction of the container in which it is to be performed and reduces the possibility of corrosive effects. Ambient pressure, and the fact that the decontaminant is a gas mixture of 12 percent ethylene oxide in Freon 12, sets the maximum concentration at ~500 mg/l.
- Controlling the temperature. Again, considerations of chamber construction and possible corrosive effects at higher temperatures indicate that a temperature close to room temperature is preferred (Table 4-7). Liquid ethylene oxide is also more corrosive than the gas. Therefore, temperatures below room temperature are not desirable.

Table 4-7. Relative Merits of ETO Decontamination Temperatures

Temperature of Processing, °C	Application of Process to Spacecraft Decontamination
25° to 30°	Heat-up time insignificant. Humidity easy to control. Holding time ca. 6 to 18 hours. Not damaging to most components. Flexible and portable equipment possible.
50° to 55°	Heat-up time long and more difficult to control. Humidity more difficult to control. Holding time ca. 4 to 6 hours. Possibly damaging to some components. Expensive, fixed equipment needed.

- Optimizing relative humidity to approximately 40 percent
- Applying the process for a specified period of time necessary to achieve maximum decontamination. This time is determined by the viable microbial population to be destroyed, ethylene oxide concentration, and relative humidity, temperature, and rate of penetration of ethylene oxide to spacecraft surfaces.

The following discussion is presented on methods to control the factors described in the previous section and to maintain the planetary vehicle in the decontamination state. These methods are incorporated in the biological contamination control plan (Section 6).

4.2.1 Contamination Control

Presterilization contamination must be controlled. The microorganisms presenting the greatest obstacle to ethylene oxide decontamination are those which are completely encased in a thick deposit of

dry materials such as dried food, insects, grease, corrosion products, and polishing compounds. Also, there will be sections of the spacecraft which will be difficult to decontaminate with ETO because of limited accessibility, e.g., hinges, joints, layers of aluminized mylar, surfaces covered with dry film lubricant. It is particularly important to limit biological contamination on these items. Control of contamination is best accomplished by clean room assembly procedures, a positive program for cleaning spacecraft parts, and storage, transportation and handling procedures which will minimize further contamination.

Studies conducted in clean rooms by many investigators show that the lowest airborne and fallout microbial contamination is in FED-STD-209, class 100 laminar flow clean rooms. Fallout contamination in this type of facility stabilizes at less than 40 viable micro-organisms per square foot over an extended period (>2 weeks) (References 20, 21, 22, 23, 24). Such tight control is probably not necessary in this application. Also, a class 100 facility is very expensive to build and maintain, and the time required to fabricate a part in it is about three times longer than required in a conventional clean room (Reference 22).

Fallout contamination in FED-STD-209 class 10,000 clean rooms equilibrates at 10^2 to 10^3 viable particles per square foot. This is about one to two orders of magnitude lower than in a class 100,000 facility (Reference 25) (Figure 4-5). Microbial burden on Lunar Orbiter, assembled in a laminar flow class 10,000 facility, averaged 131 spores per square foot at the time of system test, before shipment to the launch site (Reference 26). Unfortunately, contamination during transportation was not controlled as well, so that the burden rose to 4.5×10^4/sq ft during this period. Prelaunch checkout and fueling was conducted in a class 100,000 facility. The microbial level during these operations stabilized around 2×10^3/sq ft. These experiences demonstrate that while clean rooms can be used to control microbial contamination, their effect can be reduced by one uncontrolled event.

While adequate microbial contamination control can possibly be achieved using class 100,000 facilities, if rigid personnel controls and frequent hardware cleaning cycles are instituted, the goal is more easily achieved with a class 10,000 facility. In a class 100,000 facility, surface

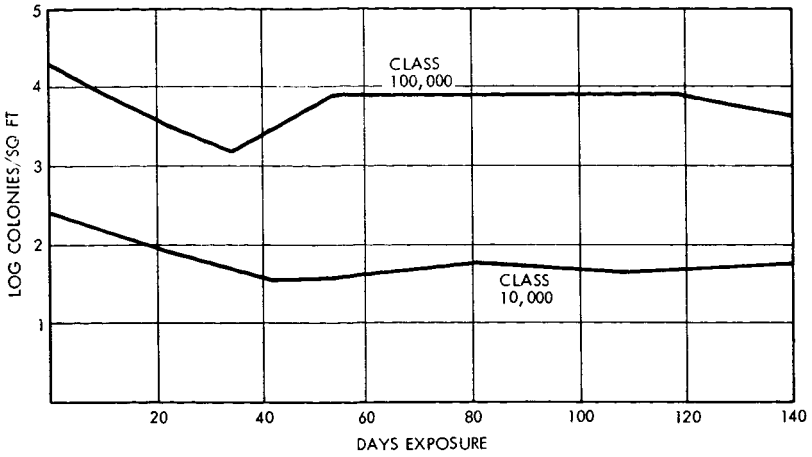


Figure 4-5
FALLOUT CONTAMINATION stabilized at ~10^2 microbes/ sq. ft in one class 10,000 facility, and at 10^4 microbes/ sq. ft in a class 100,000 facility.

contamination due to fallout alone reached 20,000 viable organisms per square foot in a 4-week sampling period (Figure 4-6) (Reference 25). Parts must thus be covered whenever possible to protect against this contamination source. Not only is the fallout contamination rate lower in a class 10,000 facility, but there are fewer large particles to harbor micro-organisms. People, the largest source of generation of contamination, are also controlled better in the latter facility. An added advantage of a class 10,000 facility over a class 100,000 is its better self-cleaning ability, enabling it to recover faster from a contaminating event.

Adherence to contamination control standards during manufacturing, test and launch operations is determined by monitoring contamination levels on hardware and in facilities. Contamination levels so measured can be used to determine frequency and adequacy of hardware cleaning and facility maintenance, and will signal breaks in contamination control.

Some applicable cleaning processes are ultrasonic scrubbing and vapor degreasing. In a study of effectiveness of cleaning processes in physically removing micro-organisms, Willard found that ultrasonic scrubbing followed by vapor degreasing to be quite efficient, removing more than 98 percent of an ~10^6 spore population of Bacillus subtilis dried on stainless steel coupons. Ultrasonic scrubbing alone was slightly less efficient, removing about 95 percent of the spores. Vapor degreasing alone removed 32 to 81 percent of the contamination (Table 4-8) (Reference 25).

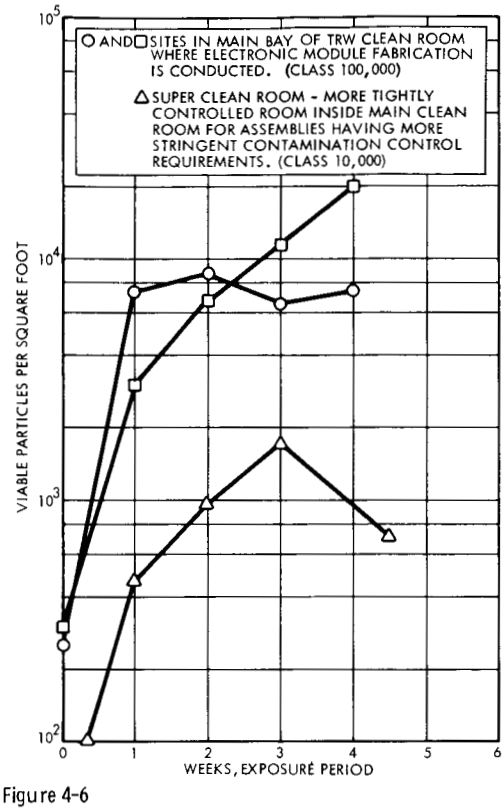


Figure 4-6

ACCUMULATION OF VIABLE CONTAMINATION on metal coupons through fallout is ten times less in a class 10,000 facility than in a class 100,000 facility.

Table 4-8. Mechanical Cleaning of Stainless Steel Coupons Contaminated with Bacillus subtilis (Inoculum: 6.9×10^4 Spores per Coupon)

Cleaning Method	Solvent	Viable Spore Population After Cleaning
Ultrasonic scrubbing, 5 minutes	Trichloroethane	3.0×10^3
	Freon TF	2.2×10^3
Vapor degreasing, 5 minutes	Trichloroethane	4.7×10^4
	Freon TF	1.3×10^4
Ultrasonic scrubbing followed by vapor degreasing, 5 minutes each	Trichloroethane	1.2×10^3
None (Control)	---	6.9×10^4

A number of solvents used in electronic component cleaning, such as trichloroethane, Freon TF, and isopropyl alcohol, are biologically clean when purchased (References 25, 27). Decontamination before use, therefore, will probably not be required.

4.2.2 Ethylene Oxide Concentration, Temperature, and Relative Humidity Control

The proper gas mixture can be purchased from commercial sources. However, it is obtained as a compressed liquid, and if not properly dispensed, can cause cooling of lines, due to the rapid expansion and volatilization of the gases, to such an extent that ethylene oxide (b.p. 54°F) will condense and separate from the Freon 12 (b.p. -21.6°F). This could present a flammability hazard and also can influence decontamination effectiveness since the ethylene oxide concentration may not be uniform.

Mobile sterilization units have been developed for delivering 12 percent ethylene oxide-88 percent Freon 12 as a uniform gas mixture, combined with water vapor to provide the correct relative humidity. The design of such a unit has been investigated for this program (Section 9). The unit should be capable of regulating and maintaining the humidified gas within the planetary vehicle compartment of the shroud for 24 hours. Pressure gauges and indicators should be incorporated on the unit for direct readout of pressure, temperature, humidity, gas concentration, gas quantity, and gas flow.

It is not desireable for the gas mixture to remain in the PVC after decontamination is completed because of the possible deleterious effect of the gas and the weight penalty for lifting this heavy gas during launch. The mobile unit thus should also have the capability of removing the sterilant mixture from the PVC and purging with sterile nitrogen. To ensure sterility, the nitrogen could pass through a bacteriological filter which had been previously sterilized in the line at the same time as the contents of the PVC.

4.2.3 Decontamination Time

Time to decontaminate can be assessed from estimates of contamination load on the spacecraft, obtained from microbiological assay

records, and by actually determining time to sterilize a planetary vehicle model. The test should be conducted in the planetary vehicle compartment using the mobile ETO unit.

4.2.4 Maintenance of Decontamination

The PVC must maintain the integrity of its contents after decontamination until it is deployed well beyond the earth's atmosphere. To do this, it should be air tight. Maintenance of a slight positive internal pressure during ground operations after decontamination, thereby preventing in-flow of contaminated air, also would be desirable. Air conditioning to the PVC should be aseptic, and the vent valve to exhaust the compartment atmosphere during launch and ascent should be designed to prevent entrance of contaminants during this period. Vent design is discussed in Volume 10.

4.3 BIBLIOGRAPHY

This bibliography lists references cited in Sections 4.1 and 4.2, and other publications on ETO thought to be of interest.

1) E. O. Haenni, et al., "New Nonflammable Formulations for Sterilizing Sensitive Materials, Ind. Eng. Chem. 51, 685, 1959.

2) R. S. Lloyd and E. L. Thompson, "Gaseous Sterilization with Ethylene Oxide, "American Sterilizer Co., Erie, Pa., 1958.

3) C. R. Phillips and S. Kaye, "Sterilizing Action of Gaseous Ethylene Oxide, "Am. J. Hyg., 50, 270-279, 1949.

4) R. T. Cotton and R. C. Roark, "Ethylene Oxide as a Fumigant," Ind. Eng. Chem. 20, 805, 1928.

5) C. R. Phillips, "Sterilizing Action of Gaseous Ethylene Oxide. II. Sterilization of Contaminated Objects with Ethylene Oxide and Related Compounds: Time, Concentration, and Temperature Relationships," Am. J. Hyg. 50, 280-288, 1949.

6) S. Kaye, "Sterilizing Action of Gaseous Ethylene Oxide. III. The Effect of Ethylene Oxide and Related Compounds upon Bacterial Aerosols," Am. J. Hyg. 50, 289-295, 1949.

7) R. K. Hoffman, "Ethylene Oxide Sterilization Rates and Protective Influences," presented at the COSPAR Symposium on Sterilization Techniques for Instruments and Materials, July 1967, London, England.

8) S. Kaye and C. R. Phillips, "The Sterilizing Action of Gaseous Ethylene Oxide. IV. The Effect of Moisture," Am. J. Hyg. 50, 296-306, 1949.

9) G. L. Gilbert, et al., "Effect of Moisture on Ethylene Oxide Sterilization," Appl. Microbiol. 12, 496-503, 1964.

10) R. R. Ernst and J. J. Schull, "Ethylene Oxide Gas Sterilization. I. Concentration and Temperature Effects," Appl. Microbiol. 10, 337-341, 1962.

11) J. B. Opfell, "Effect of Encasement of Bacterial Spores on the Sterilization Effectiveness of Exposure to Gaseous Sterilant and Application of Liquid Sterilization," Dynamics Science Corp., 1962.

12) S. D. Rubbo and J. F. Gardner, "Efficiency of Sterilants in Terrestrial and Extraterrestrial Environments," COSPAR Symposium on Sterilization Techniques for Instruments and Materials as Applied to Space Research, London, England, July 1967.

13) C. F. Abbott, J. Cockton, and W. Jones, "Resistance of Crystalline Substances to Gas Sterilization," J. Pharm. and Pharmacol. 8, 709-720, 1956.

14) A. Royce and C. Bowler, "Ethylene Oxide Sterilization - Some Experiences and Some Practical Limitations," J. Pharm. and Pharmacol. Suppl. 13, 87T-94T, 1961.

15) J. E. Doyle and R. R. Ernst, "Resistance of Spores Occluded in Crystals to Sterilization," Bact. Proc. 67, 13, 1967.

16) M. Dick and C. E. Feazel, "Resistance of Plastics to Ethylene Oxide," Modern Plastics, 148, 1960.

17) M. Willard and A. Alexander, "Surveyor Sterilization, Part IV. Studies of Sterilization Techniques," Hughes Aircraft Co., RS-293, 1962.

18) J. B. Opfell, "Synergism in Ethylene Oxide - Methyl Bromide Sterilization of Very Dry Spore and Staphylococcal Populations," COSPAR Symposium on Sterilization Techniques for Instruments and Materials as Applied to Space Research, London, England, July 1967.

19) S. Kaye, "Synergistic Effect of Ethylene Oxide and Other Agents," COSPAR Symposium on Sterilization Techniques for Instruments and Materials as Applied to Space Research, London, England, July 1967.

20) M. S. Favero, et al., 1965, "Comparative Levels and Types of Microbial Contamination Detected in Industrial Clean Rooms," Report No. 9, NASA Contract R-137, U. S. Dept. of Health, Education, and Welfare, Phoenix, Arizona.

21) H. Finklestein and R. Scheir, 1966, "Microbial Accumulation on Surfaces in Industrial Clean Rooms, "AIAA Stepping Stones to Mars Meeting, Baltimore, Maryland.

22) G. F. Kapell, J. J. McDade, and T. Gavin, 1966, "Experimental Assembly and Sterilization Laboratory (EASL) Operations: Phase 1," Report No. 32-941, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

23) F. Kutnewsky, 1965, "Laminar Downflow Sweeps Bacteria from Clean Room, Sandia Experiment Hints," Contamination Control, Vol. IV, No. 8, 11.

24) R. S. Runkle, et al., 1967, "Design of Facilities for Microbial Contamination Control," presented at 5th Semi-Annual Meeting of the Biological Contamination Control Committee of the American Association for Contamination Control, Cocoa Beach, Florida.

25) M. Willard, "Contamination Control in the Manufacturing Sequence," TRW Systems, presented at the Annual Meeting of the Society for Industrial Microbiology, London, Ontario, August 1967.

26) R. L. Olson and R. H. Green, "Laboratory Investigations Relating to a Systems-Analysis Approach to Planetary Quarantine," The Boeing Co., presented at the COSPAR Symposium on Sterilization Techniques for Instruments and Materials, July 1967, London, England.

27) R. J. Varga, "Surveyor Spacecraft System. Final Sterilization Report," Vol. I and II, Hughes Aircraft Co., SSD3372R, June 1963.

28) John B. Opfell, et al., "Ethylene Oxide Sterilization of Spores in Hygroscopic Environments," J. Am. Pharm. Assn., Scientific Edition, XLVIII, No. 11, 617, 1956.

29) M. Willard and A. Alexander, "A Self-Sterilizing Coating for Spacecraft Surfaces," Nature, 202 No. 4933, 658-659, 1964.

30) Ethylene Oxide, Chemical Safety Data Sheet, SD-38, MCA, Inc.

31) G. W. Jones and R. E. Kennedy, "Extinction of Ethylene Oxide Flames with Carbon Dioxide," Ind. and Eng. Chem., 22, p. 146, 1930.

32) E. O. Haenni and R. A. Fulton, "Aerosol Sterilants," Soap and Chemical Spec., 35, p. 101.

33) S. Kaye and B. F. Sierkiewicz, "Methods and Equipment for Sterilization with Ethylene Oxide Vapor," Abstract of papers presented at the 122nd Meeting of the Am. Chem. Soc., Atlantic City, N. J., September 1952.

34) R. S. Lloyd and E. L. Thompson, Gaseous Sterilization with Ethylene Oxide, American Sterilizer Co., Erie, Pa., 1958.

35) Walter J. Miklas, Development of Ethylene Oxide-Freon Decontaminant in 16 Ounce Disposable Containers, Biological Labs, Ft. Detrick, Md., January 1958.

36) J. J. Perkins, "Gas Sterilization," Drug and Cosmetics Ind., 87, pp. 178-180, August 1960.

37) Charles R. Phillips, "Gaseous Sterilization," Becton, Dickson Lectures on Sterilization, Seton Hall College of Medicine and Dentistry, 1958.

38) C. R. Phillips, "Gas Sterilization," Drug and Cosmetics Ind., 82, p. 802, June 1958.

39) C. R. Phillips, Gaseous Sterilization, Lea and Febiger Publishing Co., Philadelphia, Pa., 1954.

40) C. R. Phillips, "Practical Aspects of Sterilization with Ethylene Oxide Vapor," Bact. Proc., 50th Meeting Soc. Am. Bact., pp. 23-24, 1950.

41) W. H. Stryker, "Gas Sterilization," Hospital Management, pp. 74-77, March 1958.

42) K. H. Sroka, "A Review of Health Hazards Caused by Ethylene Oxide, Ethylene Glycol and Its Esters and Other Polyhydric Alcohols," Seifen-Ole-Fette-Wachse, 80, 1954.

43) "Efficiency of Carboxide Gas as an Insecticidal Fumigant for Naval and Merchant Vessels," Reprint F-4880, Union Carbide Chemical Co.

44) J. D. Fulton and R. B. Mitchell, "Sterilization of Footwear," U. S. Armed Forces Medical Journal, 3, pp. 425-439, 1952.

45) "Fumigation with Ethylene Oxide," P. B. 103, 785, His Majesty's Stationary Office, February 1951.

5. SPACECRAFT DECONTAMINATION DESIGN REQUIREMENTS

5.1 PROPULSION AND REACTION CONTROL SUBSYSTEM REQUIREMENTS

The purpose of the ETO process is to decontaminate surfaces which may be sources of contaminated efflux. All external surfaces of the Voyager spacecraft are so classified, thus are to be subjected to a terminal ETO decontamination after spacecraft enshroudment in the planetary vehicle compartment.

In addition, any spacecraft subsystem should be separately decontaminated if it could produce contaminated efflux during the mission from internal surfaces that may not be exposed to the gas in terminal decontamination. A detailed examination of the spacecraft configuration was made to determine items which fall into this category. Consideration was given to the location of the item on the spacecraft, type of construction, and probability of causing contamination of Mars or the capsule at any stage of the mission.

5.1.1 Propulsion and Reaction Control Subsystems

The propulsion and reaction control subsystems produce efflux deliberately. Examination of the propulsion subsystem reveals, however, that most items of the subsystem are either:

- In contact with the liquid propellants which are sporocidal
- Swept by the propellants—contaminated particles so carried are burned with the propellants and are therefore sterilized
- Accessible to ETO during terminal decontamination.

Special decontamination of these items therefore is not required.

The storage system for the helium pressurization gas of the propulsion module is not sterilized by any of these mechanisms, but the unit is sealed. The only nitrogen gas deliberately expelled is admixed with propellant which should sterilize it. Decontamination of this unit

therefore is not required unless the probability of rupture and release of viable micro-organisms exceeds permissible levels. Analysis of this potential failure mode is being conducted as part of the Voyager reliability program.

The attitude control gas system utilizes nitrogen gas which is not self-sterilizing. Quarantine analysis has shown that the probability of the system causing contamination of Mars will exceed permissible levels if contaminated gas is used.* Therefore decontamination of this item is required.

5.1.2 Sealed Units

A number of sealed units have been identified which contain free volume. These include drive mechanisms, actuators, tape recorders, and photo-imaging units. If they remain sealed during the mission, contaminants will not be released. Decontamination of these items therefore is not planned unless failure analysis reveals a probability of rupture and release of viable micro-organisms which exceeds permissible levels.

5.2 QUALIFICATION TEST REQUIREMENTS

Reliability considerations require that compatibility of the spacecraft be with ETO decontamination assured. This is accomplished by performing qualification and acceptance tests at appropriate levels.

ETO flight acceptance tests are considered desirable for flight units and the spacecraft even though ETO is a nonoperating environment for the spacecraft, because: 1) ETO decontamination is a novel spacecraft environment; therefore, a history of experiences on which to base judgments of spacecraft performance is meager; 2) physical access to the spacecraft will not be allowed after terminal decontamination; the spacecraft test allows more extensive checkout; and 3) the ETO test serves to reduce the biological load on surfaces not easily accessible to the gas, such as joints and layers of superinsulation; this reduces

*Voyager Spacecraft Phase 1A Task B Final Technical Report, Volume 1, "Preferred Design: System Considerations," Appendix E, "Biological Contamination," TRW 5410-6001-R0V01, January 17, 1966.

the time required for terminal decontamination. Conditions simulating the maximum exposure for one terminal decontamination are considered sufficient for acceptance testing. Considering the complexity of the spacecraft, an 11-hour exposure after stabilization of the decontaminating environment in the PVC will probably be needed for terminal decontamination. Adding fill and flush time may increase the total time to 24 hours for ETO exposure.

ETO qualification tests are necessary on materials and components, units, and the spacecraft test model. Tests at the unit and spacecraft levels yield data on the influence of design and packaging on ETO compatibility. Qualification tests should be performed under more stringent conditions than expected for flight hardware. Since flight hardware is exposed to three ETO cycles (two flight acceptance tests and one terminal decontamination), six cycles for qualification is considered appropriate. A 10^{o}C increase over the flight exposure temperature and 5 percent higher relative humidity is also specified for qualification test. A typical scheme for qualification of materials and components is presented in Figure 5-1.

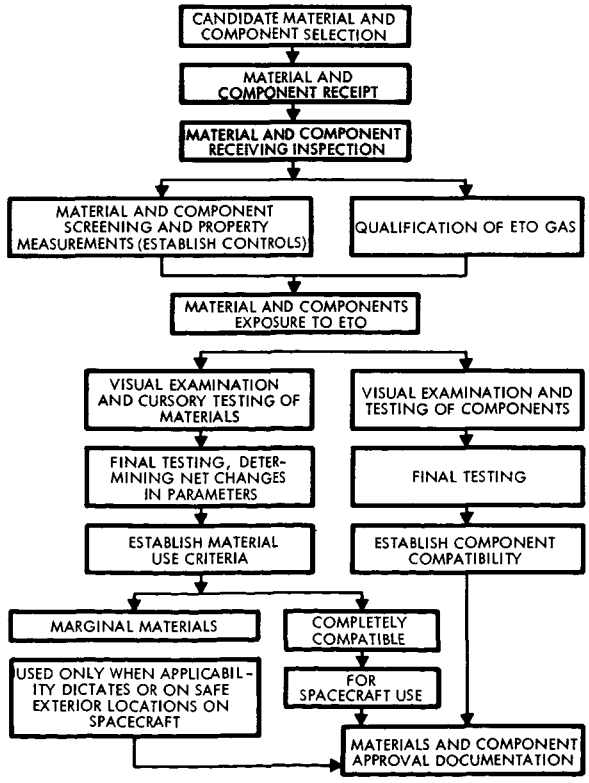


Figure 5-1

FLOW CHART shows scheme for materials and components qualification for ETO exposure.

6. BIOLOGICAL CONTAMINATION CONTROL PLAN

The biological contamination control plan establishes the control of biological load buildup during manufacture of the spacecraft, and specifies necessary decontamination procedures for spacecraft subsystems and the completed spacecraft assembly. It is based on requirements for effective decontamination discussed in the previous sections. The basic features of the plan are:

- Clean room assembly, integration, and test from the unit through the system levels
- Mechanical cleaning and chemical disinfection of assemblies to reduce microbiological and particulate loads
- Internal sterilization of units which could produce viable spacecraft efflux during the mission
- Terminal decontamination with ETO of the mated spacecraft and encapsulated lander within the planetary vehicle compartment (PVC)
- Aseptic air-conditioning of the PVC following terminal decontamination.

The plan is diagrammed in Figures 6-1, 6-2, 6-3, and 6-4, and is detailed in the following sections. For the purposes of the plan, piece parts are defined as individual components (resistors, integrated circuits, valves, actuators, cables), modules (electronic welded cordwood modules, matrix boards), or subassemblies which make up a unit. A unit is defined as a combination of piece parts or subassemblies to make a functional entity (computer and sequencer, decoder, engine). A unit may or may not be a subsystem. System refers to the entire flight spacecraft.

6.1 COMPONENT AND PIECE PART LEVEL

Piece part fabrication and assembly (Figure 6-1) are conducted in a controlled environment, but not in clean rooms unless strict particulate contamination control on the part is needed. Cleaning is instituted where

appropriate to remove gross contaminants. Apart from particulate contamination control considerations, the primary object of the cleaning is to eliminate contaminant sources which are difficult to sterilize, such as dirt, grease, and corrosion products. An additional contamination control measure is to include only those materials which are fungus resistant on the approved materials and parts lists for Voyager.

Microbiological assay is conducted on parts selected at random from the production line in order that records can be maintained on microbial load data. Parts are prepared for unit assembly by thorough washing to reduce contamination levels to those suitable for entrance of the part into a FED-STD-209, class 10,000 facility. If not immediately assembled, parts are packaged in clean nylon bags which meet cleanliness level 1 of PR 2-2.* They are then placed in bonded stores to await unit assembly.

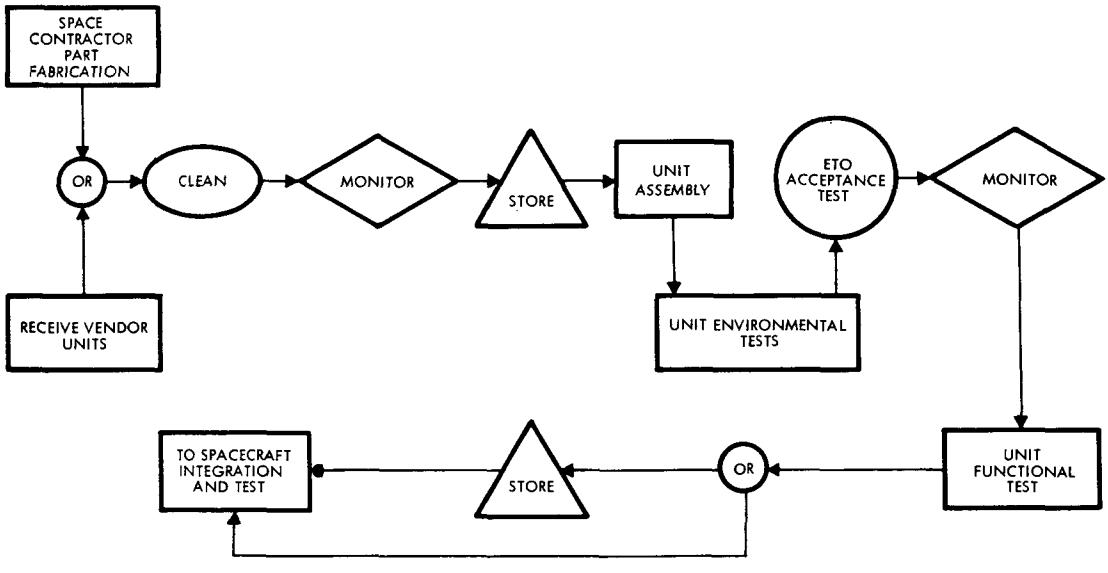


Figure 6-1

PIECE PART AND UNIT FABRICATION, ASSEMBLY AND TEST CONTAMINATION CONTROL involves clean manufacture and unit ETO acceptance test.

6.2 UNIT LEVEL

Unit assembly (Figure 6-1) is conducted in rooms meeting the requirements of FED-STD-209, class 10,000 with additional limits establishing permissible concentration of viable particles in the ventilation inlet air, in the room air, and in surface fallout. Microbio-assays follow the procedures delineated in NASA "Requirements for Bioclean Facilities." The number of people within the rooms is limited and all persons are required to wear lint-free coats, head and shoe covering. Air washes are required of personnel before they don clean overgarments.

Prior to unit assembly, a sampling of a batch of parts is made for microbiological assays. If surface biological contamination levels exceed 10^3 viable organisms per square foot, parts are cleaned. Applicable processes include: vapor degreasing, ultrasonic scrubbing, flushing with ultraclean fluids, ultraclean air washing, and vacuum cleaning.

During the unit assembly period, parts are protected from aerial fallout by storage and transportation in plastic bags or covered containers. Items are cleaned as necessary. Bonded stores, dated labels, written records of the history of the unit, and limited microbial assays are utilized to estimate surface contamination at a particular time.

Unit flight acceptance testing includes one 24-hour ETO exposure. This test serves also as a decontamination procedure. The ETO test is scheduled last in the flight test sequence in order to minimize handling, and therefore contamination, of the unit prior to spacecraft assembly.

After flight acceptance tests, the unit is packaged in a clean nylon bag and moved to the spacecraft assembly area or to bonded stores. Transportation by means other than hand carrying may require that the unit also be packaged in a clean shipping container.

*TRW Process Specification, PR 2-2, "Cleanliness of Fluid System Components."

6.3 SYSTEM LEVEL

6.3.1 Assembly, Integration, and Test

Spacecraft assembly, integration, and test (Figures 6-2 and 6-3) are also performed in class 10,000 facilities. Where possible, OSE and checkout equipment are located in adjacent areas with electrical feedthroughs to the clean room in order to minimize the number of objects and people in the clean area, and in order to avoid the need for equipment designs that are compatible with clean room operation.

Vacuum cleaning constitutes the primary method of reducing microbial loads. Biological assays are conducted periodically to insure against excessive contamination buildup and as a check against breaks in contamination control.

When the spacecraft is transported between facilities, it is packaged in a shipping container which has been cleaned to cleanliness level 1 of PR 2-2. Humidity in the shipping container is controlled to less than 30 percent relative humidity. Transportation over long distances or during adverse weather conditions requires that air-conditioning provisions be utilized.

Spacecraft flight acceptance testing includes one 24-hour ETO exposure. This test serves also as a decontamination procedure. It is particularly important for decontaminating the numerous layers (70) of aluminized Mylar which will cover most of the exterior of the spacecraft. Thorough decontamination of the layers at this stage will help to reduce the time required for the terminal process. The ETO test is scheduled last in the flight test sequence in order to minimize contamination of the spacecraft prior to packaging for shipment to KSC.

For transportation to KSC, the spacecraft is packaged in a shipping container which meets cleanliness level 1 of PR 2-2 and in which the humidity is controlled to < 30 percent relative humidity. Clean air-conditioning is provided which maintains class 10,000 conditions in the shipping container.

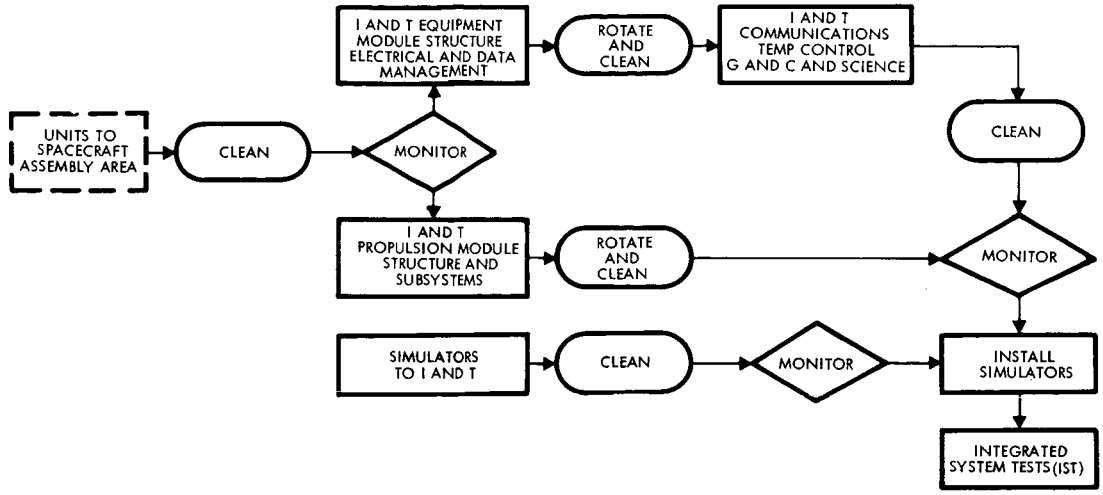


Figure 6-2

THE PRIMARY METHODS OF CONTAMINATION CONTROL during spacecraft assembly and integration are clean room handling and daily vacuum cleaning.

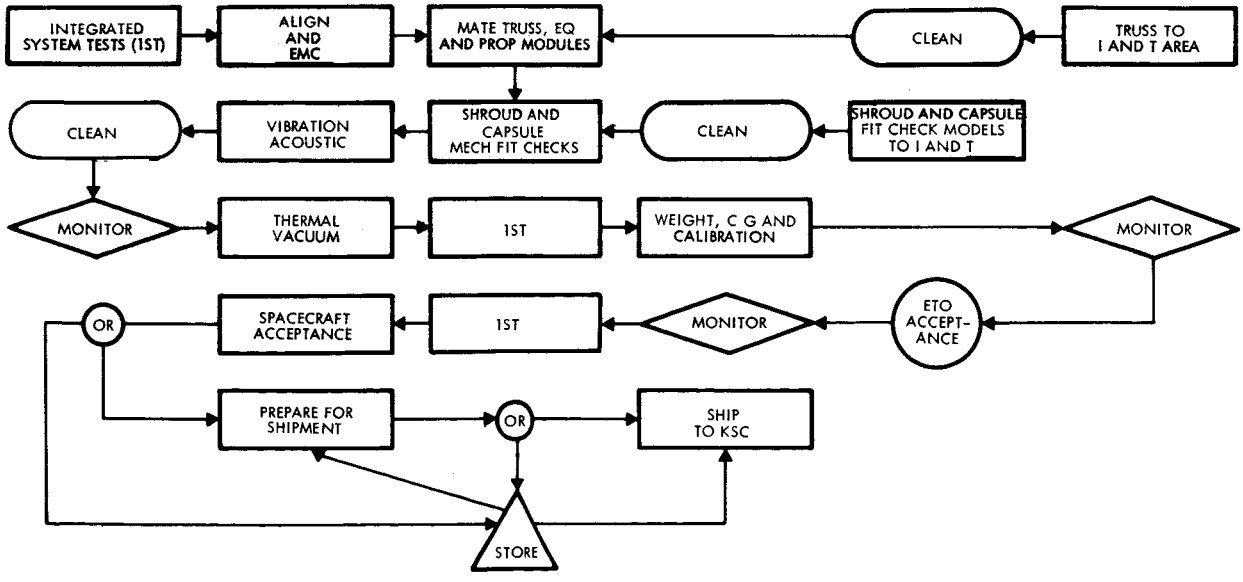


Figure 6-3

CLEAN ROOM FACILITIES are utilized throughout system tests. An ETO acceptance test results in reduction of viable microbial loads.

6.3.2 Launch Operations

6.3.2.1 Handling, Integration, and Test

All launch operations from spacecraft receipt through PVC mating are conducted in class 10,000 facilities under the same controls specified for unit and spacecraft assembly (Figure 6-4). Regularly scheduled monitoring operations for both particulate and biological control are conducted. Vacuum cleaning constitutes the primary method of removing surface contaminants. All spacecraft and planetary vehicle integration and test operations are closely controlled and monitored to insure that contamination control requirements are met.

6.3.2.2 Reaction Control Decontamination

The reaction control hardware is decontaminated and loaded prior to mating the spacecraft and the lander. The procedure for doing this is as follows. All but one exit port of the hardware is capped. A bacteriological filter and two spore strips (sterility indicators) are placed in the final exit port line which is then connected to a vacuum system. A valve is inserted between the exit port and the vacuum line. A bacteriological filter is also placed ahead of the gas fill valve. This line is connected to an ETO sterilizing unit and to the reaction control gas source. The regulator and solenoid valves are opened and the hardware is evacuated (to < 1 in. Hg), then filled to 15 psia with ETO at 30 ±2°C, 40 ±5 percent relative humidity. The inlet and exit valves are closed. After 6 to 11 hours,* the inlet and exit valves are opened and ETO is removed from the system by applying vacuum (< 0.1 mm Hg). The exit valve, solenoid valves, and regulator are closed. The gas tanks are then filled with nitrogen through the inlet bacteriological filter. The valve is closed, and the bacteriological filters, spore strips, and exit port caps are removed. The spore strips are tested for viability in order to certify adequate decontamination of the reaction control subsystem.

6.3.2.3 Propellant Loading

Propellant start tanks are loaded prior to terminal decontamination. The most recent MSFC guidelines specify a capability for propellant loading on the launch pad. Such an operation would seriously

*Exposure time depends on the contamination load.

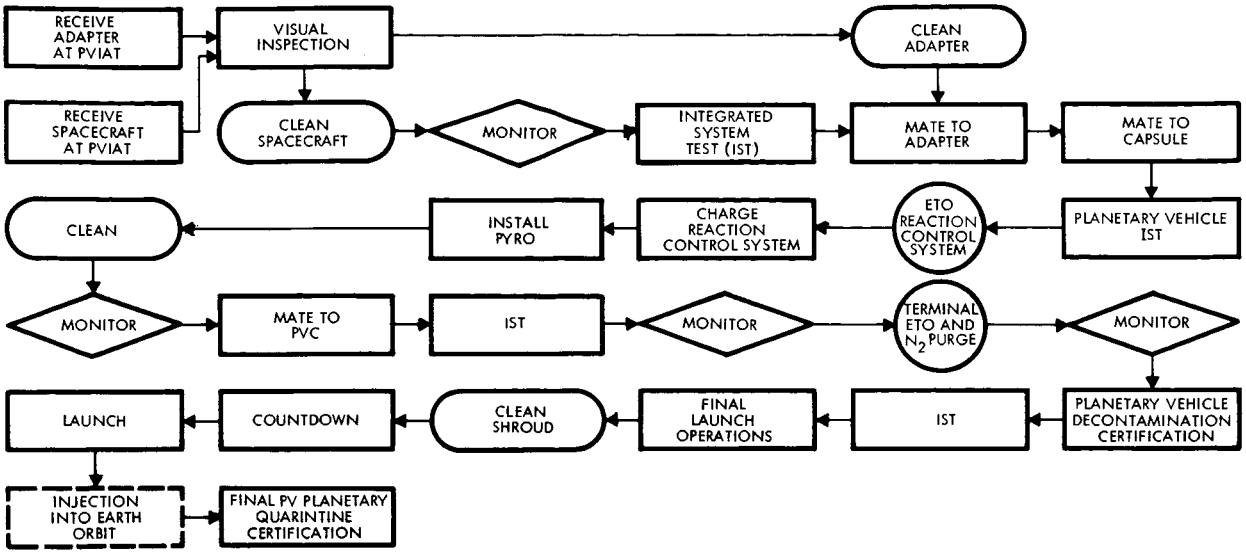


Figure 6-4

TERMINAL ETO DECONTAMINATION is performed at the launch site on the PVC. The RCS is decontaminated separately before PVC mating. Assay of the spacecraft biological load is made to establish the ETO cycle

complicate maintenance of biological cleanliness. It may be possible to fill the storage tanks on the pad without recontaminating the PVC, but filling of the start tanks is better performed prior to terminal ETO.

An additional importance is attached to the final leak checks of the propulsion system before PVC encapsulation because the propellants react readily with ethylene oxide.

6.3.2.4 Planetary Vehicle Enshroudment and Decontamination

A final biological monitoring operation is conducted prior to final planetary vehicle enshroudment, to assess the total planetary vehicle biological load. This data is used to establish the ETO cycle.

Surface decontamination of the completed flight spacecraft and the lander capsule is conducted in the PVC after completion of system tests. Handling controls to prevent rupture of the capsule seal during mating operations are established.

The PVC is equipped with valves and bacteriological filters for filling with sterilant gas, purging, and pressure equalization during ambient temperature fluctuations during storage. A valve is also present which is designed to open on command at a predetermined pressure differential, to permit rapid exhaustion of the shroud atmosphere during launch and ascent.

Prior to decontamination, the PVC contents are heated to 32°C with warm nitrogen containing 40 ±5 percent relative humidity. Decontamination is then accomplished by filling with ETO at 40 ±5 percent relative humidity. Since liquid ethylene oxide can be corrosive, the gas mixture is heated to 40°C before introduction to the PVC to make sure that it is completely vaporized. A continuous flow of gas is maintained in the compartment to insure uniform ETO composition. A pressure slightly above ambient conditions is maintained. Duration of the exposure is 9 to 18 hours, depending on the contamination load and time for adequate penetration of ETO throughout the spacecraft surfaces. At the completion of the cycle, the compartment is flushed with sterile dry nitrogen. Physical access to the PVC contents is not allowed after terminal decontamination.

A mobile unit is utilized for the ETO source. The unit must be capable of regulating and maintaining the ETO concentration and humidity level within the PVC for 24 hours. Pressure gauges and indicators are incorporated on the unit for direct readout of pressure, temperature, humidity, gas concentration, gas quantity, and gas flow.

Certification of decontamination is based on adherence to the prescribed procedures, including the proper pressure, temperature, humidity, gas concentration, flow, fill time, exposure time, and purge time. In addition, recoverable spore samples are placed in the exit line of the PVC, to be tested for viability at the conclusion of the decontamination cycle. Decontamination certification is made prior to transportation of the PVC to the launch pad.

Maintenance of particulate and biological contamination levels after terminal decontamination is assured by providing a constant 0.5 psig internal pressure in the PVC, and by providing biologically filtered coolant gas through the shroud during the prelaunch and final countdown sequence.

Cleanliness of the exterior of the PVC during transportation and on the launch pad is maintained by covering it with a clean plastic bag. A final cleaning of the exterior is performed just prior to launch.

6.4 CONTROLS

6.4.1 Spacecraft Compatibility

Materials and components used in the construction of the spacecraft are qualified for ETO exposure to insure no degradation of spacecraft life as a result of terminal decontamination. Qualification tests are also performed at the unit and system levels. The spacecraft proof test model is to be used for system qualification test. The test consists of determining satisfactory performance after six 24-hour exposures to ETO at 15 psia, 40°C, and 45 ±5 percent relative humidity.

Flight acceptance tests are also specified for flight units and the flight spacecraft. The test involves one 24-hour exposure to ETO at 15 psia, 30°C, and 45 ±5 percent relative humidity.

A sample specification incorporating requirements and procedures for the ETO tests is presented in Appendix 2.

6.4.2 Terminal Decontamination Effectiveness

Proof of the decontamination procedure is conducted on the spacecraft proof test model. Viable spores are placed at various locations, including places not easily accessible to ethylene oxide. To make recovery possible without introducing contaminants, the spores are enclosed in a material through which ethylene oxide could easily diffuse, such as paper or plastic envelopes or cotton-stoppered glass tubes. The PTM is sealed in a PVC model which is filled with ETO, using the mobile ETO decontamination unit. Pressure, temperature, humidity, gas concentration, and gas flow are carefully monitored and rigidly maintained at the desired levels. Conditions are maintained for 11 hours, after which the PVC is purged with nitrogen and the spores recovered and tested for viability.

This procedure is repeated if results indicate a design-related resistance to the effects of ETO. Causes of failures are traced and eliminated. The proven procedure is then used for terminal decontamination.

6.4.3 Assay and Cleaning Procedures Verification

Microbiological assay and cleaning procedures for clean rooms, parts, units, and the spacecraft are developed as part of the engineering effort during Phase C and verified during construction of the spacecraft proof test model.

6.4.4 Training Program

A program is conducted to indoctrinate and train personnel in the objectives and execution of the contamination control program. Participation includes management, engineering, and manufacturing personnel. Biological and particulate contamination control requirements are integrated in the training program.

7. MATERIALS AND COMPONENTS SELECTION

7.1 INTRODUCTION

This task was approached from a subsystem level. For each subsystem, contact was made with the responsible engineer. He was asked to identify any material or component that could come into contact with ETO gas, i.e., any non-hermetically sealed items. In many cases the subsystem had not been designed in enough detail to allow identification of the materials and components to be used. In these instances one of two approaches were taken: a) the engineer was asked to identify any materials that might be considered for use on the unit in question; b) lists of materials and components were taken from similar units used on other programs.

A problem was encountered in identifying materials and components for the spacecraft science subsystem. Most of this subsystem is comprised of government-furnished equipment (GFE) which has not yet been designed. Since the sources from which the government will procure these items are diversified, there will be a minimum of conformity in the choice of materials and components for each piece of equipment.

The data on the ETO compatibility of materials and components was obtained from: a) a TRW literature survey covering data up to 1965 (20);* b) ETO compatibility studies conducted at TRW as part of the LM Engine Demonstration program (Reference 25); c) a TRW test program on marking and identification materials (Reference 23); d) a search of post 1965 literature through IDEP and STAR; and e) communications with NASA centers.

The compatibility studies completed so far include a wide variety of materials, components, and ETO exposures. One report presented general remarks on ETO effects, ETO as a plasticizing agent, impurity reactions both in the sterilant and in the materials, and the reaction of some metal surfaces as catalysts, especially in liquid ETO. Another report covered 68 polymeric products under an ETO environment very similar to that required by the ETO qualification test specification.

*Numbers refer to references listed in Appendix A.

There are four studies presently in progress on material and component-ETO compatibility. Two are contracts for component testing. There have been no published reports on these tests as yet. Another program involves ETO compatibility testing on seals, gaskets, tie cords, lacing tape, structural materials, films and sheets. The fourth is part of the Voyager LM Demonstration program conducted by TRW for MSFC.

The references to the compatibility studies are given in Appendix A. Applicability of the literature data for evaluation of Voyager material and component compatibility with ETO was assessed by comparing the exposure conditions with those specified in the sample ETO Qualification and Acceptance Test specification (Appendix B).

7.2 SUMMARY

7.2.1 Comparison of ETO Compatibility Data Exposures and Sample ETO Qualification Test Requirements

The ETO compatibility data from each of the studies were derived from varied gas exposures. The length and temperature of exposure to the ETO gas is the key to interpreting what that material will do under the sample ETO test specification exposure which defines a) gas composition, b) relative humidity, c) temperature, d) length of exposure, and e) number of cycles. A comparison between exposures is done in Table 7-1 on the major literature sources. From this table it can be seen that much of the test data is based on exposures similar enough to the sample ETO Qualification Test Specification to be meaningful. Two of the major compatibility studies (References 19, 20) are for exposures with similar environment but only one-third the length of exposure. Such data demonstrate problem areas that occur during short exposures and cannot ensure that other problem areas will not occur on longer exposures. However, the trend of most of the data indicate that it is unlikely that major problems will develop.

7.2.2 Comparison of ETO Compatibility Data With Subsystem Materials

From all known ETO data a rating was made as to ETO compatibility with each of the subsystem materials. The results are listed by material

Table 7-1. Comparison of ETO Compatibility Test Exposures (Literature Data) With Sample ETO Qualification Test Specification

Compatibility Data Source/ Reference	Decontamination Gas Mixture	Relative Humidity	Temperature	Length of cycle (hr)	No. of Cycles	Similar to the Sample ETO Qualification Test Specification
Sample ETO Qualification Specification	12% ETO/88% Freon 12, 500 ±50 mg ETO/l	45 ±5%	40°C	24	6	
Muraca, Polymers for Spacecraft Hardware (Ref 22)	12% ETO/88% Freon 12	~50%	50°C	28	6	Comparable
Al Mylar tests (Ref. 24)	12% ETO/88% Freon 12	Varied (45-100%)	Varied	30	6	Comparable
Willard and Zobel, ETO Effects on Components (Reference 20)	12% ETO/88% Freon 12, 600 mg ETO/l	50%	50°C	18 to 36 for components; 48 hrs ETO plus 108 hrs heat for materials	48	Length of exposure is shorter
Elastomeric Seal Rupture (Ref. 17) Analysis	12% ETO/88% Freon 12 & Freon 11, 17 psig	None	55°C	6 65	1 1	No humidity; shorter exposure
Rydelek and Landis, ETO Effects on Polymers (Ref. 19)	12% ETO/88% Freon 12, 10 psig	(dew point between 66 & 78°F)	74°F and 104°F	24	1	1/3 the length of exposure
Calvit, Markings and Identification (23)	12% ETO/88% Freon 12, 760 mmHg	35 to 50%	50°C	28	6	Comparable
TRW, Voyager Engine Materials-ETO Compatibility Study (Ref. 25)	12% ETO/88% Freon 12, 600 mg/ETO	50±5%	50°C	28	7	Comparable

types in Tables 7-2 to 7-25. The key to the ratings is given below. The data and reasons for choice of ratings are discussed in the following sections.

C = Compatible; sufficient test data show no detrimental ETO effects.

TC = Tentatively compatible; test data indicate compatibility but is insufficient for a conclusive judgement, or no test data is available but item is expected to be compatible because of its chemical nature.

M = Marginal; test data indicates unsuitability for some applications, or significant degradation of some parameter is shown.

TM = Tentatively marginal; limited exposure test data indicate material may be marginal upon longer exposure, or no test data is available but item is expected to be marginal because of its chemical nature.

NC = Not compatible; test data show major degradation.

TNC = Limited exposure data indicate major degradation may occur on longer exposure, or no test data but item is expected to be incompatible because of its chemical nature.

7.2.2.1 Lenses (Table 7-2)

Lens materials are rated either compatible or tentatively compatible. The quartz lens is itself compatible with ETO. However, if there is any contamination on the lens there is the possibility that the ETO may condense and form a film.

Magnesium fluoride is usually used as an antireflective coating on lenses, solar cells and sensors. There is no data on its compatibility with the decontamination atmosphere. It is known that a similar compound, magnesium chloride, reacts in water solution with ethylene oxide:

1) $MgCl_2 + 2\ HOH \rightarrow Mg(OH)_2 + 2\ HCl$

2) $HCl + H_2C\overset{O}{\diagdown\!\diagup}CH_2 \rightarrow H_2C(Cl)-CH_2(OH)$

The magnesium fluoride film, however, will probably not react to any noticeable degree in this way because it will be in a gaseous humid environment (~40 percent RH) rather than in water solution. Even at higher relative humidities there would be little chance of the magnesium fluoride reacting because it is poorly soluble in water at room temperature, and its solubility decreases with increasing temperature. This is in direct contrast to $MgCl_2$. Consequently, it is assumed that even though almost 100 percent of the magnesium fluoride is exposed to the humidity and the ETO, there would be minimal reaction. Tests should be run to confirm its compatibility prior to use.

A vacuum deposited optical filter is sandwiched between each solar cell and its coverglass. The composition of the film is vendor proprietary and there is no compatibility data known. However, only the very edge of the film will be exposed. It is not expected that the ETO or humidity will sufficiently come in contact with the film to cause degradation anywhere except the edges, if degradation should occur at all.

Table 7-2. Compatibility Rating for Lens Materials

Materials	ETO Compatibility Rating*	Remarks
Quartz lens	C	
Magnesium fluoride anti-reflective	TC	See Section 7.2.2.1
Optical filter, proprietary	TC	Only edges of film will be exposed.

7.2.2.2 Propellants (Table 7-3)

The propellants to be used, monomethylhydrazine and nitrogen tetroxide, react with ethylene oxide. Special precautions will have to be made to ensure that the ETO does not come in contact with them.

*C = Compatible; TC = tentatively compatible; NC = not compatible.

Table 7-3. Compatibility Ratings on Voyager Bipropellants

Materials	ETO Compatibility *Rating	Remarks
Monomethyl hydrazine	NC	Do not allow to come in contact with ETO
Nitrogen Tetroxide	NC	

7.2.2.3 Ablative Materials (Table 7-4)

The ablative materials for the combustion chamber are listed as tentatively compatible. In tests conducted at TRW all materials exhibited some bleaching after ETO exposure, which, however, was not severe (Reference 25). MX 2600 suffered 17.8 percent tensile strength decrease and 32.8 percent modulus decrease. These are significant, but the results are suspect due to wide variations noted in control and test specimen tensile test values. It was felt by the experimenter that this was caused by improper curing of the specimens. WB 7208 exhibited a tensile strength decrease of 16 percent. MX 2600 and WB 7208 gained 3.4 percent and 7.6 percent weight, respectively.

Table 7-4. Voyager Ablative Materials—ETO Compatibility

Materials	ETO Compatibility Rating*	Remarks
MX2600 (Phenolic Silica Laminate)	TC	For this application see Reference 25
MXSE57 (Rubber Modified Phenolic Silica Laminate)	TC	For this application see Reference 25
WB7208 (Insulation Overwrap)	TC	For this application see Reference 25

*C = Compatible
TC = Tentatively compatible
NC = Not compatible

Tests should be rerun on properly cured specimens of these materials to confirm compatibility. These tests should include firing the material to determine possible degradation of ablative properties.

7.2.2.4 Lubricants (Table 7-5)

While lubricants are potentially soluble in ETO, tests run here at TRW showed that those lubricants expected to be used in the Voyager engine are compatible. This includes the DuPont 240 AC Lube which was expected to decrease in viscosity following ETO exposure. After testing in an environment comparable to the sample qualification test environment, it was shown to increase rather than decrease in viscosity, and it retained its lubrication value (Reference 25).

In the guidance and control subsystem, the thrust vector control equipment will use an oil with magnetic particles suspended in it. The oil to be used is unidentified. Testing will be necessary to ensure that it is compatible.

Lubricants will also be found in the gyros and tape recorders. However, in both cases the designs of the units are such that the greases are sealed off from ETO exposure and pose no problem.

Other lubricating compounds which have been tested in ETO and found to be compatible are DC5 silicone grease and F-50 silicone fluid. DC 200 silicone fluid, on the other hand, is not compatible (Reference 19).

Table 7-5. Voyager Lubricants - ETO Compatibility Rating

Materials	ETO Compatibility Rating*	Remarks
Lubco 2023 Dry Lube	C	Reference 25
Microseal Dry Lube	C	Similar to Lubco 2023 but no test data
DuPont Krytox 240-AC Lube	C	Reference 25
Magnetic Particle Suspension Oil	TC	No data; should be tested
Glass-Filled Teflon (Rulon A)	C	Reference 25

*C = Compatible
TC = Tentatively compatible

7.2.2.5 Wire Insulations and Sleevings (Table 7-6)

Ten types of insulated wire are presently designated for use on the Voyager engine. Six are rated compatible with the ETO exposure (Reference 25). An enamel insulated wire (MIL-W-583 type F) is not considered compatible and another material will have to be substituted for it. The polyimide-coated teflon insulation is considered compatible but this should be verified prior to use since some polyimides (notably H-film) are known to undergo considerable degradation during ETO exposure. A silicone enamel (MIL-W-583 type H) should similarly be tested to ensure suitability.

Table 7-6. Voyager Wire Insulations and Sleevings - ETO Compatibility Rating

Materials	ETO Compatibility Rating*	Remarks
Polyimide-Coated Teflon	TC	Reference 25
High-Temperature Teflon TFE MIL-W-583 Type K	C	Reference 25
Enamel MIL-W-583 Type F	NC	Substitute another enamel; Reference 25
Formvar or Formex MIL-W-583 Type T	C	Reference 25
Cotton MIL-W-583 Type C	C	Reference 25
Silk MIL-W-583 Type S	C	Reference 25
Glass MIL-W-583 Type G	C	Reference 25
Thermaleze "F" MIL-W-583 Type L	C	Reference 25
Silicone Enamel MIL-W-583 Type H	TC	Reference 25
Tubing and Sleeving		
Polyvinyladene fluoride (Kynar) AMS 3632	C	Reference 23, 25
Polyolefin MIL-I-23053	M	Reference 23 - marginal, becomes tacky on exposure to ETO, replace w/kynar Reference 25 - NC, No data or explanation given, replace w/kynar
Teflon MIL-I-22129	C or M	Reference 20 - M, Absorbs Freon 12, replace with kynar. Reference 25 - C, No data
Silicone Rubber Over Fiberglass, MIL-I-3190	TC	No data
Polyvinylchloride and Its Co-Polymers, MIL-I-631	TC	PVC is rated C (Reference 20); No data on co-polymers
Siliflex (Braided Fiberglass with Silicone Resin)	C	Reference 25
Fiberglass with Fungicide, Dowcide #7, Added to Varnish	C	Reference 25
Extruded Vinyl Plastic MIL-I-7444	C	Reference 25
Triple Saturated Cotton	C	Reference 25

*C = Compatible
TC = Tentatively compatible
NC = Not compatible
M = Marginal

Polyolefin sleeving becomes tacky during ETO exposure (Reference 23). Effects on its dielectric and mechanical properties are not known. It has therefore been listed as marginal. Kynar sleeving would probably be a better choice.

While teflon is compatible, it does absorb Freon 12. Again it would be better if Kynar, which has no reaction to the ETO, is used.

Polyvinyl chloride has been tested and found to be compatible. No tests have been run on its co-polymers. Therefore, they have been rated as tentatively compatible.

7.2.2.6 Insulation Tapes (Table 7-7)

There is no data on the ETO compatibility of the insulation tapes expected to be used on Voyager, except on a polyester film insulation tape which has been rated compatible. Varnished cambric is expected to be incompatible with ETO. Although the other insulation tapes may undergo some changes during exposure to the ETO atmosphere, the changes are not expected to be sufficient to render the tapes unusable for insulation. They are therefore rated as tentatively compatible, pending test data.

Table 7-7. Compatibility Rating on Insulation Tapes

Materials	ETO Compatibility Rating*	Remarks
Acetate film cloth thermo-setting adhesive	TC	Reference 25
Glass cloth/silicone MIL-I-19166	TC	Reference 25
Cambric, Varnished	TNC	Replace with kynar or Teflon
Epoxy Impregnated Glass Fabric	TC	Reference 25, 22
Velcro Tape	TC	
Crepe Paper	TC	
Paper	TC	
Acetate Cloth MIL-I-15126	TC	Reference 25
Teflon Film/Silicone Adhesive	TC	Reference 25
Elastic Vinyl MIL-I-7798	TC	Reference 25
Polyester Film MIL-I-1526	C	Reference 19, 25

*C = Compatible
TC = Tentatively compatible
NC = Not compatible
TNC = Tentatively not compatible

7.2.2.7 Elastomers and Seals (Table 7-8)

This appears to be an area in which extreme care must be exercised in the selection of materials. A number of marginal and incompatible formulations have been listed. Compatible alternates also exist, however.

Included as marginal elastomers are neoprene, fluorosilicones, and fluorocarbons. Some formulations of these types exhibit significant losses in tensile properties after less than 48 hours exposure to the gas (Reference 19). The property changes are not unacceptable, but the deterioration is expected to increase with increase in ETO exposure. The effects are probably due to the ETO dissolving in the elastomer. These materials are rated as marginal rather than tentatively incompatible because they must be suitable for static applications where high mechanical strength is not needed.

Table 7-8. Compatibility Ratings on Elastomers and Seals

Materials	ETO Compatibility Rating	Remarks
AMS 3303/60 Silicone	C	Small Hardness increase after 2 ETO cycles, Reference 19
Hadbar 1000/80 Silicone	C	Reference 19
Hadbar 4000/80 Silicone	TC	8% tensile loss, hardness change +5 after 2 ETO cycles 5, Reference 19
Hadbar 5000/80 Silicone	C	
Hadbar 7000/80 Silicone	TC	10% tensile loss, hardness change +5 after 2 ETO cycles 5, Reference 19
L-308-80 Fluorosilicone	C	Reference 19
L-449-6/60 Fluorosilicone	C	Reference 19
MIL-R-5847/50 Silicone	C	
MIL-R-5847C/70 Silicone	C	
PMP 6100 Silicone	C	7% tensile loss, Reference 19
PR 1930-1/2 Silicone	C	
PR 1930-2 Silicone	C	
RTV 560 Silicone	C	3.5% volume increase after 2 ETO cycles, Reference 19
RTV 615 A/B Silicone	C	Reference 19
S 417-7 Silicone	C	Reference 19
VITON B60 Fluorocarbon	C	Reference 19
VITON B90 Fluorocarbon	M	15% tensile strength decrease after 2 ETO cycles, Reference 19
VITON A, Linear 8250-85 Fluorocarbon	C	8% tensile strength decrease after 1 ETO cycle, Reference 20
Neoprene W Parco 363-70	M	16% tensile strength decrease, 20% ultimate elongation decrease after 1 ETO cycle, Reference 20
LS-53, Stillman TH1057 Fluorosilicone	M	18% tensile strength decrease, 18% ultimate elongation decrease after 1 ETO cycle, Reference 20
Buna N, Precision 758-70	TC	14% ultimate elongation decrease after 1 ETO cycle, Reference 20
Teflon O-ring	C	Reference 19
Kynar	C	Reference 23
Butyl O-ring	C	Reference 25
EPR O-ring	C	Reference 25
MIL-S-22473 (Loctite) sealing compound	C	Reference 25
Nitrile O-ring	NC	Reference 25
Nitroso rubber	NC	Reference 25
PR5-9 Silicone rubber	C	Reference 25

It must be noted that not all fluorosilicones and fluorocarbons are marginal. A fluorosilicone, L-449-6/60, and many fluorocarbons are compatible with ETO.

EPR and butyl rubber O-rings have been shown to be compatible with the required ETO exposure. Loctite sealing compound and Kynar seals are also compatibible (References 22, 25).

Teflon seals may dissolve Freon 12 but do not otherwise degrade. Teflon seals could be used, but Kynar may be used to replace the teflon if the absorption of Freon 12 is deemed undesirable. Nitrile rubber O-rings show large gains in weight and thickness, and have not been rated compatible (Reference 25).

An elastomeric Kel-F seal on a capacitor was observed to swell when exposed to either ETO or Freon 12. Extended exposure caused rupture (Reference 17). Such seals will have to be replaced by another material or another component chosen. This particular Kel-F seal had additional proprietary ingredients in it. Kel-F is not normally incompatible with ETO.

7.2.2.8 Surface Coatings (Table 7-9)

No data is available on the coatings expected to be used on Voyager. In the study of sterilization problems by R. Calof and associates (Reference 18) an epoxy flat black paint and Cat-a-lac black were rated as compatible but not data were given. The torque and white Cat-a-lac paints are expected to be similar to the Cat-a-lac black paint. These paints are listed as tentatively compatible and should be tested before they are used.

Table 7-9. Compatibility Ratings on Surface Coatings

Paints		
CAT-A-LAC Black	TC	Reference 18
CAT-A-LAC White	TC	Should be the same as the CAT-A-LAC Black
CAT-A-LAC Torque	TC	Reference 25
Epoxy (PR 5-2), black & white	TC	Reference 18
Polyester (PR 5-13) velvet black (3M)	TC	No data
Rinshed-Mason (aluminum color)	TC	No data

7.2.2.9 Miscellaneous Silicones (Table 7-10)

The silicones listed in Table 7-10 are suitable only for applications where tensile strength is not a requirement (Reference 25).

RTB-11 shows loss in mechanical strength in ETO (Reference 19). There is no data on RTV 580. It is expected to be compatible for non-structural use.

Table 7-10. Compatibility Rating on Miscellaneous Silicones

Material	ETO Compatibility Rating	Remarks
HA-1 (MIL-I-180-57 Cond. E)	TC	Reference 25
MIL-R-5847-1	TC	Reference 19
RTV - 580	TM	
RTV - 11	C/M	Depends on use (Reference 19, 20)
RTV 601/11	C	For non-structural use (Reference 25)
Silicone Insulator	TC	Reference 20

7.2.2.10 Superinsulation and Thermal Control Tapes (Table 7-11)

Aluminized Mylar has been tested and found compatible with the decontamination environment. However, there has been a report that this material is sensitive to humidity levels that might exist during ETO exposure (Reference 24). Since aluminized Mylar is a key material on the Voyager spacecraft, we conducted an experimental investigation to assess in detail the effects of relative humidity. Crinkled, flat, and dimpled sheets as well as a crinkled Mylar blanket were tested. These tests were run at relative humidities from 50 percent to 100 percent. Emissivity tests were run on the aluminized Mylar both before and after humidity testing to determine the amount of degradation of the thermal insulation properties (Table 7-12, Figure 7-1). As a result of the tests the following conclusions were reached (Reference 26):

1. An aluminized Mylar blanket does not degrade when exposed to a 55 percent relative humidity.

2. Slight aluminum surface degradation occurs when the aluminized Mylar is exposed to a relative humidity of 88 percent. It is felt that this degradation is caused by spot condensation.

3. When the insulation blanket is exposed to Voyager decontamination, a maximum relative humidity of 50 percent should be set. Since the ETO qualification is at 45 ±5 percent, the Mylar blanket should be compatible.

4. To guarantee that there will not be localized condensation on the insulation blanket during terminal decontamination, the following steps are to be taken:

   a. Provide blanket perforations.

   b. Preheat the PVC contents.

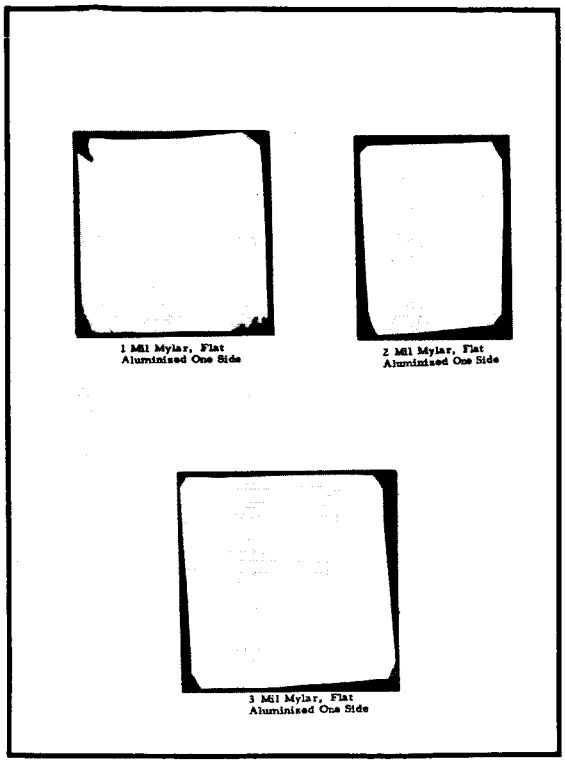
   c. Premix the water vapor with the decontamination gas before injection.

   d. Maintain good circulation of the decontamination mixture.

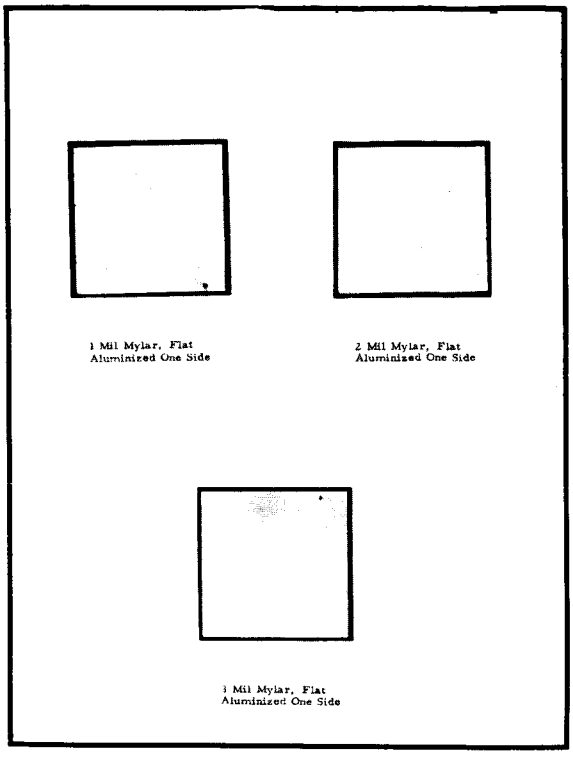
   e. Maintain good temperature control of the decontamination mixture.

Table 7-11. Compatibility Ratings on Superinsulation and Thermal Control Tapes

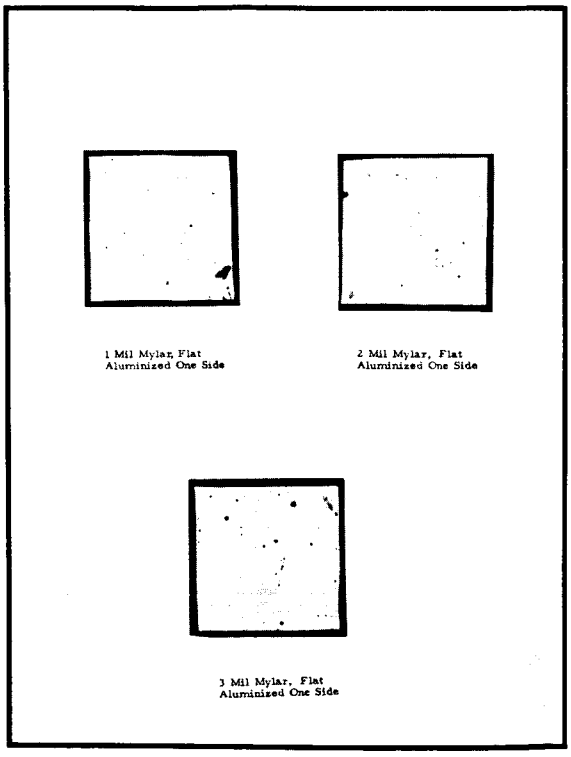
Material	ETO Compatibility Rating	Remarks
Y-984 A gold tape	TC	No data
Y-984 S gold tape with silicone adhesive	TC	No data
Mystic 7402 aluminum tape with silicone adhesive	TC	No data
Al Mylar	C	
Cu (clear or blackened) clad mylar	TC	No data



BEFORE HUMIDITY EXPOSURE



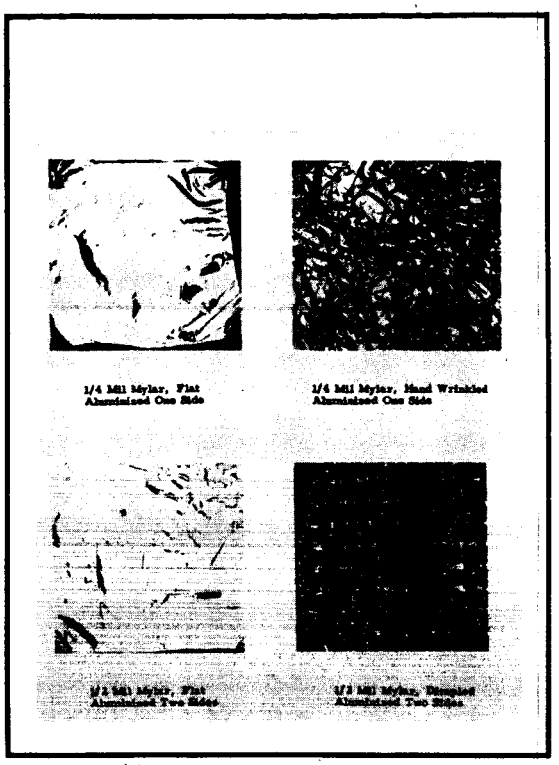
AFTER EXPOSURE TO 55% Rh, 122°F, FOR 144 HOURS



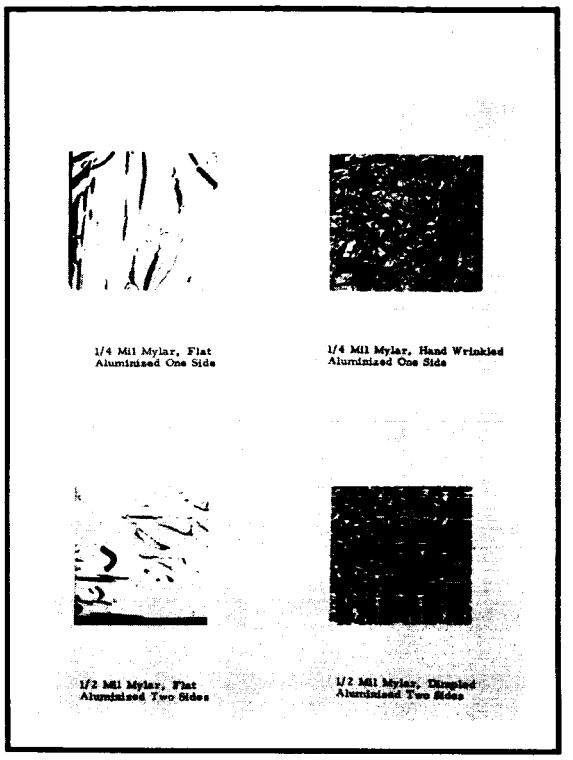
AFTER EXPOSURE TO 88% Rh, 122°F, FOR 144 HOURS

FOLDOUT FRAME

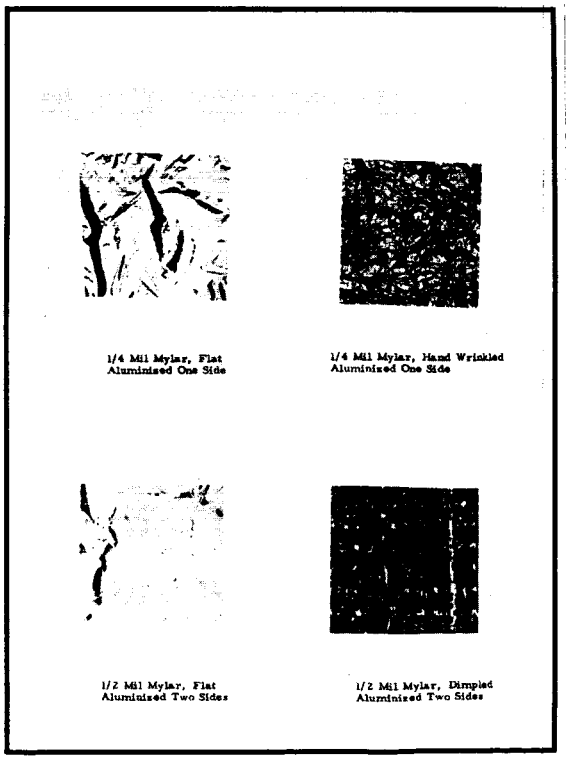
7-14



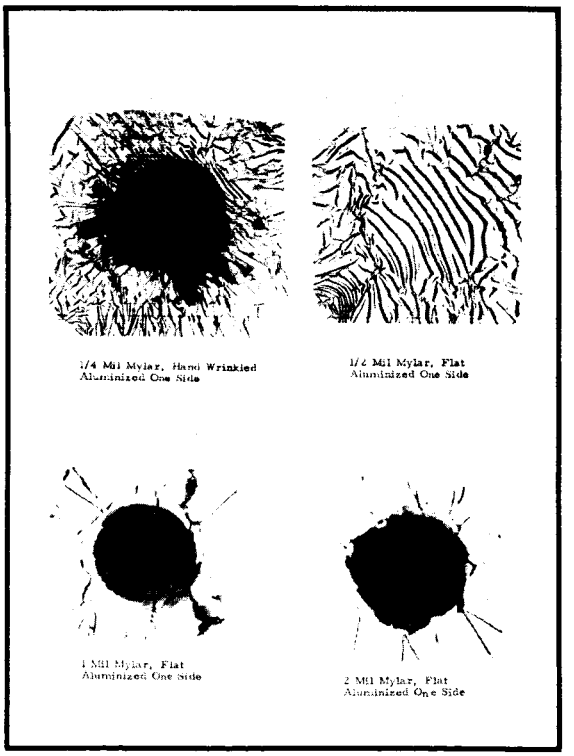
BEFORE HUMIDITY EXPOSURE



AFTER EXPOSURE TO 55% Rh, 122°F, FOR 144 HOURS



AFTER EXPOSURE TO 88% Rh, 122°F, FOR 144 HOURS



AFTER EXPOSURE TO 100% Rh, 122°F, FOR 144 HOURS

Figure 7-1

ALUMINIZED MYLAR demonstrates sensitivity to moisture at 88% and 100% relative humidities, but not at 55% relative humidity.

FOLDOUT FRAME

There are no data on copper clad Mylar or on the thermal control tapes. They are rated as tentatively compatible.

Table 7-12. Effect of Relative Humidity on Aluminized Mylar (Reference 26)

Sample	Aluminum Surface Emissivity Prior to Exposure	Aluminum Surface Emissivity After 55% RH Exposure (144 hours)	Aluminum Surface Emissivity After 88% RH Exposure (144 hours)
1/4 mil flat	0.03	0.03	0.03
1/4 mil wrinkled	0.09*	0.13*	0.10*
1/2 mil flat	0.05	0.07	0.05
1/2 mil dimpled	0.34*	0.32*	0.33*
1 mil flat	0.03	0.03	0.02
2 mil flat	0.03	0.03	0.03
3 mil flat	0.03	0.03	0.02

*Reading is high because of surface configuration.

7.2.2.11 Adhesives (Table 7-13)

Many epoxy and silicone adhesives are rated compatible, allowing adequate selections. Many adhesives are partially degraded by the ETO decontamination exposure, however. Losses in tensile strength have been noted in some cases.

Sylgard 182 has been tested and found to undergo an 87 percent loss in tensile strength and 4.4 percent loss in elongation; swelling also occurred. In spite of these considerable changes taking place, the Sylgard 182 is suitable for application in the propulsion module as an interface material since a surface of only 0.060-inch thickness is exposed to the environment. It is probably not suitable for other uses.

Shear strengths of Epibond 104 and Epoxylite 5302 have been found to decrease significantly after 24 hours exposure to ETO. These decreases do not degrade the materials for structural applications, but more degradation may occur with longer exposures. These materials are therefore rated as tentatively marginal.

The epoxy-silver adhesives are listed as marginal because of the discolorations noted after exposure. In applications where only thin edges are exposed, the amount of degradation may be minimal and may not affect the overall functioning of the adhesive.

Table 7-13. Compatibility Ratings on Adhesives

Materials	ETO Compatibility Ratings	Remarks
Epon 934	C	Reference 25
HT 427	C	Reference 25
Hysol A9-5150/H2-3690 Epoxy	TC	No data
Hysol A9-5150/H8L-3543 Epoxy	TC	No data
Epon 828/Versamid 140 Epoxy	TC	No data
Sylgard 182 Silicone	M	Good for some applications; Reference 25
Sylgard 182 Optical Grade	M	No data, should be the same as the non-optical grade
Sylgard 187 Silicone	TC	No data
Sylgard 183 Silicone	TM	No data
Sylgard 184 Silicone	TM	No data
PR 4-15 Type 1 Class 3 (D.C. XR-6-3489)	TM	A purified Sylgard 182
D.C. 92-018 Silicone with Carbon Filler	TM	No data
D.C. 1200	TM	No data
D.C. 675	TM	No data
Adiprene L-100 Polyurethane	TM	No data
D.C. 90-092 Silicone	TC	No data
Eccobond 56C Conductive Epoxy	TM	No data
Eccobond 57/C Epoxy/Amine Silver	M	Surface stains and blisters after gas exp. (Reference 19)
Epon 828/A Epoxy/Amine	C	Reference 19
Epon 8/A Epoxy/Amine	C	Reference 19
Epon 828/Z Epoxy/Amine	C	Reference 19
Epon 901/B-1 Epoxy	C	Reference 19
Epon 901/B-3 Epoxy	C	Reference 19
E-Solder 3022 Epoxy/Silver	M	Badly stained (Reference 19)
FM-96 Epoxy/Nylon	C	Badly stained (Reference 19)
RTV 108 Silicone	M	Reference 19
RTV 140 Silicone	C	Reference 19
RTV 891 Silicone	C	Reference 19
FM 1000 Epoxy Polyamide	C	Reference 20
Epoxylite 5302 Epoxy	TM	17% shear strength decrease after 24 hour exposure (Reference 20)
Epibond 104 Epoxy	TM	12% shear strength decrease after 24 hour exposure (Reference 20)
Eccobond 45 Launch Vehicle	C	8% shear strength decrease after 24 hour exposure (Reference 20)
Hysol C 15-020 Epoxy	TC	No data
Hysol K 8-4238 Conductive Epoxy	TM	No data

7.2.2.12 Potting and Encapsulating Materials (Table 7-14)

All potting and encapsulating materials on which test data were available are rated as compatible.

Some deterioration has been noted in electrical properties of DC 881, Eccoseal W-19, and Stycast 2651.

Other encapsulants for which no compatibility data exist but which are similar to those that have been tested are rated as tentatively compatible.

Test data is not available on the polyurethane encapsulant, but sorption studies on a polyurethane showed five mole percent ethylene oxide uptake by the resin (Reference 19). This material therefore may be marginal.

Table 7-14. Compatibility Ratings on Potting and Encapsulating Resins

Material	ETO Compatibility Rating	Remarks
Stycast 2651/cat. 11 epoxy	C	Percent dissipation factor increased from 0.165 to 1.51 (Reference 19)
Eccoseal W 19/cat. 11 epoxy	C	Dielectric constant increased from 4.50 to 4.65 (Reference 20)
Stycast 1090/cat. 11 epoxy	C	Reference 20
Epon 826 amine cured	C	Reference 20
Epon 826 anhydride cured	C	Reference 20
Epon 828 amine cured	C	Reference 20
Epon 828 anhydride cured	C	Reference 20
DC 881 silicone	C	Dielectric constant increased from 2.97 to 3.23 (Reference 20)
Truecast 111	TC	No data
Hysol XC8-H789/ H8L-3543	TC	No data
PR 1535 polyurethane	TM	No data
PR 4-16 epoxy (C15-015)	TC	No data

7.2.2.13 Laminates (Table 7-15)

Laminates are generally rated as compatible with ETO. Micarta H-2497 and Laminate EGH-5834 are listed as marginal because of significant volume increases after two 24-hour exposures to ETO.

Gas exposure has caused increase in tensile strength of some materials, and decrease in tensile strength of others (Reference 19). All changes are acceptable, however.

Table 7-15. Compatibility Ratings on Laminates

Materials	ETO Compatibility Ratings	Remarks
EG 758T Epoxy/Glass Cu Clad	C	Reference 19
FG-91 LD Phenolic/Glass	C	Reference 19
Laminate EG 752 Epoxy/Glass	M	11% volume decrease (Reference 19)
Lam Grade H-5834	C	Reference 19
Phenol/Glass Laminate NS	C	Reference 19
Phenol/Nylon Laminate 500J	C	Reference 19
Epoxy/Glass Cu Clad Micarta Grade 238	C	Reference 19
Phenol/Linen Micarta GX	C	Reference 19
Epoxy/Glass Micarta H-2497	M	5% volume increase after two 24-hour exposures (Reference 19)
Epoxy/Glass Micarta LE-221	M	Reference 19)
Phenol/Linen Micarta 8457	C	Reference 19
Epoxy/Glass XP-206	C	Reference 19
Epoxy/Glass		

7.2.2.14 Marking and Identification Materials (Table 7-16)

Only EC 200 is rated as incompatible. This material showed heavy deterioration on 9 of 20 substrates on which it was tested. Warnow red, yellow, and black inks are not compatible with ETO when used on a TFE substrate, but show only slight degradation on 19 other substrates. This is probably because initial adhesion to TFE is poor. Brady B-600 labels and Sprint Film are not at all affected by the exposure.

Table 7-16. Compatibility Ratings on Marking and Identification Materials

Materials	ETO Compatibility Rating	Remarks
Independent 73X, Green	C	
Independent 73X, Black	C	
Independent 73X, Blue	C	
Independent 73X, White	C	
Independent 73X, Yellow	C	
Wornow M, Yellow	M	Not suitable on TFE substrate, but compatible on nineteen other substrates
Wornow M, Red	M	Not suitable on TFE substrate, but compatible on nineteen other substrates
Wornow M, White	C	
Wornow M, Black	M	Not suitable on TFE substrate, but compatible on nineteen other substrates
Sprint Film	C	
Brady B-600	C	
EC-200	NC	Loses adhesion

7.2.2.15 Miscellaneous Organic Materials (Table 7-17)

Included in this category are plastics, foams, and molding compounds. Compatibility data are lacking on many of them. These are rated according to results obtained in tests on materials somewhat similar to them. For

example, there is no data on TYRIL 767, an acrylic polymer (acrylonitrile-styrene). A similar material for which there is test data is polystyrene. This material becomes crazed after long exposures to ETO, but the crazing is not sufficient to rate it incompatible. From these results the TYRIL 767 is rated as tentatively compatible. It should be tested to verify suitability for ETO exposure.

Table 7-17. Compatibility Rating on Miscellaneous Voyager Materials

Materials	ETO Compatibility Ratings	Remarks
Fiberfrax (no organic binder)	C	Reference 25
Chlorinated Polyether Straps	TNC	Reference 25
RTV Silicone foam	TC	Reference 25
Phenolic, Synthane	C	Reference 25
Delrin 500	C	Reference 25
Glass filled Diallyl Phthalate	C	Reference 19
Stur-d-lace 18D96 Nylon Cord with Synthetic Rubber finish	C	Reference 25
MIL-P-22241 TFE plastic sheet	C	Reference 25
Fluorosilicone with Chomerics Powder No. 8000	TC	Reference 25
D.C. 679	TM	No data
Refrasil	TM	No data
Eccofoam FPH polyurethane	TM	No data
B-Chemical M1709 Epoxy (over Vacuum Deposited Al)	TC	No data
Unidentified (proprietary) Molded Epoxy (ITT connectors)	C	Reference 20
Mesa Plastic GPI-30 FS4, Unmilled without Pigment	C	Reference 19
H-Film	NC	50% tensile strength decrease (Reference 19)
400 Flex Strip	TC	No data
TYRIL767 - Lucite (arcylic polymer) acrylo-nitrile-styrene	TC	No data (Reference 20)
TR4-13 Polyurethane Foam Core	TC	No test data
SMP 62/63 Impregnated Glass Cloth	TC	No data
Fabroid Spherical bearing	C	Reference 25
Magnetic tape	TNC	

The only material in this group rated not compatible is H-film. It suffers 50 percent decrease in tensile strength after two 24-hour cycles in ETO (Reference 19). In an attempt to determine the cause of degradation, one investigator analyzed the residual gas after exposing the H-film. The analysis showed that most of the ethylene oxide had been scavenged by the test specimen, leaving an atmosphere of Freon 12. Exposing the specimen to a vacuum did not remove the sorbed ethylene oxide. The mechanism of the gas-material interaction is not clear (Reference (19).

Fabroid spherical bearings show a slight increase in friction due to the ETO exposure, but are considered compatible (Reference 25).

Some magnetic tapes are degraded by ETO. There is not enough information to determine whether this is true of all magnetic tapes. However, tape recorders are sealed and the sensitive material should not contact the ETO.

7.2.2.16 Nonmetallic Inorganic Materials (Table 7-18)

Ceramics (e.g., alumina and beryllia) are not expected to react with ETO. Similarly, glass (e.g., corning fused silica type 7940 or fiberglass) is inert (Reference 20). These are rated compatible.

Table 7-18. Compatibility Ratings for Inorganic Materials

Materials	ETO Compatibility Ratings	Remarks
Fiberglass	TC	No test data
Corning Fused Silica Type 7940	C	Inert
Ceramic Preform	C	Inert
Ceramics		
Alumina	C	Inert
Beryllia	C	Inert
Sylgard Filler (PR 4-17)	TC	Inorganic; no data

7.2.2.17 Metals (Table 7-19)

Although not every metal has been tested for ETO compatibility, those which have been tested have been found to be compatible with the decontamination gas. Some metals and anodic finishes (e.g., silver, copper, brass, bronze, anodized Al) can catalyze the polymerization of liquid ethylene oxide if moisture is present, but the required decontamination exposure to 12 percent ethylene oxide-88 percent Freon 12 gas in 45 percent RH is not known to have any similar effects (Reference 20). One study showed that iridite finish on aluminum can easily be rubbed off after exposure to ETO (Reference 23). It should be determined whether or not this renders the iridite finish on the aluminum unsuitable for use on the Voyager.

Table 7-19. Voyager Metallic Materials - ETO Compatibility Rating

Material	ETO Compatibility Rating	Remarks
#180 Alloy	C	No data
Aluminum, Iridite Finish MIL C 5541	TNC	Reference 23
Aluminum, Anodize Finish	C	Reference 20
Aluminum, 70 75, 60 61, 20 24 Polished or Machined	C	Reference 18, 20
Aluminide	C	Reference 25
Aluminum - honeycomb 5052H39	TC	Reference 18
Beryllium, Anodize Finish	TC	No data
Columbium, Sheet, and Coating	C	No data
Copper	C	Cu polymerizes liquid ethylene oxide, but should be compatible with the gas atmosphere
Copper-Nickel Alloy 73 Cu-27 Ni	C	
Gold Plating	C	Reference 20
Ferrite -	TC	No data
Synthetic Ferrite		No data
Inconel X-750 MIL N 6840	C	Reference 20
Indium	C	Reference 25
Nickel	C	Reference 20
Electroless Nickel Plating	C	Reference 20
Silver Plating	C	Can catalyze polymerization of liquid ethylene oxide (Reference 20); finely divided silver probably not compatible (Reference 19).
Sinite D-10	C	Reference 25
SN/60	C	No data
SN/63	C	No data
62% Sn, 36% Pb, 2% Ag	TC	No data
Carbon Steel	C	
Steel, MoS_2 Finish	C	Reference 19, 20
Stainless Steel 302, 303, 304	C	Reference 20
Tin Coating, Plating	C	Reference 20
Titanium, Black Anodize	TC	No data
Titanium (6Al 4V)	C	Reference 20
Tungsten-Carbide	C	No data

7.2.2.18 GFE Materials

No compatibility table is presented on GFE materials because of sparsity of information on these units.

A potential problem is noted in the photo-imaging equipment in the spacecraft science subsystem. The photographic film will probably dissolve ethylene oxide and thus will likely be incompatible. However, the photo-imaging equipment design presently seals off the photographic film from any possible exposure to ETO, and as long as the seals do not rupture there will be no problem with film degradation.

7.2.3 Comparison of ETO Compatibility Data with Subsystem Components

The compatibility ratings for components are given in Tables 7-20 through 7-25 along with their construction materials. Material identification was necessary for a compatibility judgment on the non-tested components. Very little test data were available on components. Most ratings were based on the report by M.T. Willard and E.R. Zobel, "Study of Ethylene Oxide Effects on Components." (Reference 20)

Any component whose entire external construction consisted only of metal, glass, or other materials that are known to be compatible with the ETO was rated "C" (compatible) or "TC" (tentatively compatible — no test data). This includes glass-to-metal hermetically-sealed components. However, if any cracks develop in the glass seal, the device may become susceptible to internal degradation should the ETO migrate into the internal part of the component.

All components with partial or total construction of plastic materials whose compatibility is unknown were rated "TM" (tentatively marginal). These components should be tested prior to inclusion in equipment design.

7.2.3.1 Semiconductors (Table 7-20, 7-21, and 7-22)

All transistors, diodes and microcircuits are rated compatible or tentatively compatible. Tests have been conducted on a number of these components in which they were exposed to ETO for 36 hours at 104°F. No degradation was observed. Reverse leakage current was measured on diodes, and voltage and current measurements were made on transistors (Reference 20).

Table 7-20. Components Compatibility Ratings—Transistors

Component	Materials	ETO Compatibility Rating
2N2978, TO-18 2N2222, TO-18 2N2222A, TO-18 2N2907A, TO-18 2N2484, TO-18 2N2978, TO-18 2N2907A, TO-18 2N2396a, TO-18	Kovar, gold-plated leads	C
2N2501 2N3014 MD2369F	Alumina, gold-plated leads	C
2N3501, TO-5 2N2851(S), TO-5 2N3350, TO-5	Kovar, gold-plated leads	C
2N2880 2N4002 2N3499 2N3503 2N2848 2N3467 SA3839 2N3252 2N915 2N3251 2N3209 2N3954	Kovar, gold-plated leads	C
MD3251AF, TO-89 2N2946, TO-46 RM8052D, TO-84	Kovar, gold-plated leads	C C C

Table 7-21. Components Compatibility Ratings—Diodes

Component	Materials	ETO Compatibility Rating
IN7461, DO-14 IN759, DO-14 IN3604, DO-14 IN3600, DO-14 IN4571A, DO-14 IN4572A, DO-14 IN4573A, DO-14 IN823, DO-14	Glass, gold-plated leads	TC
PS3538, DO-4 MMMC1203, DO-4 PD9049, DO-4 BLV-14FS, DO-4 PD9050, DO-4 PD9752 (S), DO-4 IN3893, DO-4	Glass, Au-plated leads	TC
IN831AM	Glass, Au-plated leads; or D.C. polymer	TC

Table 7-22. Components Compatibility Ratings—Microcircuits, Flip-Flops, Gates, etc.

Components	Materials	ETO Compatibility Rating
CS701 DTμL932 SG709G CS700 SE124 SE110 SE105G SE101G SE160	Kovar, Au-plated leads	C
DTμ933, TO-86 LPDTμ9041, TO-86 LPDTμ9040, TO-86	Ceramic	TC
LPDTμ9042, TO-86	Glass, Au-plated leads	TC
LSG05 SE480J	Ceramic Au-plated leads	TC
SE124, TO-88	Ceramic, Au-plated leads	TC

7.2.3.2 Connectors and Resistors (Table 7-23)

Connectors and resistors are rated tentatively compatible. In tests on resistors, which included wirewound, carbon composition, metal film, carbon film, and trimpots, only some carbon resistors and a Bourns trimpot demonstrated minor electrical changes after a 24-hour soak in the gas. The changes were not significant since they could occur just during shelf-aging of the resistors (Reference 2).

Microdot Series 43 connectors containing silicone grommets showed no deterioration in dielectric strength but suffered decrease in insulation resistance after sterilant exposure. Insulation resistance values were within specification limits. When the silicone grommets were removed prior to exposure, insulation resistance was unaffected (Reference 2).

Table 7-23. Voyager Components Compatibility Ratings—Connectors and Resistors

Component	Materials	ETO Compatibility Rating
Resistors		
HR10 (Shallcross) HRL-417 (Kelvin)	High temperature epoxy	TC
AGS-3 (Dale)	Tinned Ni, TFE teflon sleeve, high temperature silicone coating (proprietary)	TC
EB (Allen BB Bradley)	Solder coated Cu, molded jacket; resin and silica (proprietary)	TC
FD340-62 (Filmohm)	Epoxy impregnated fiberglass, fused quartz, Ag coating	TC
HR12-83 (Daven)	High temperature epoxy resin, No. 180 alloy, Au, Cu-Ni, Ni or tinned Cu	TC
FH10 FH11 FH12 (Mebco) FH25	Au-plated Ni hard glass kovar	TC
Connectors		
PT2-82-5 PT2-82-6 (Amphenol)	Au-plated: P-Bronze Be-Cu and Brass Teflon Ray-chem SCL heat shrink tubing - polyolefin kynar	TC
PT2-16-1 (ITT Cannon or Cinch Mfg.)	Au-plated brass	C

7.2.3.3 Inductors, Filters, Transformers, and Oscillators (Table 7-24)

No compatibility data were found on these components. They are rated as tentatively compatible or tentatively marginal, depending on their materials of construction.

Table 7-24. Voyager Components Compatibility Ratings—Inductors, Filters Transformers, and Oscillators

Component	Materials	ETO Compatibility Rating
Inductors		
93233 (Vanguard)	Tinned, copper leads Furane 3B-3C system filler MG-1 Hysol epoxy case	TM
MG50-22 (Torotel)	Sn-coated steel case Solder coated No. 52 alloy leads	TC
Filters		
1200-025 (Eire Technological Products)	Glass seals Ag-plated washer, nut, and steel case and terminals	TC
PT4-1039-1 (Eire) 1200-003 (Eire) 1250-005 (Eire)	Sn-plated, Cu terminal Ag-plated steel case Ag-plated washer and nut Epoxy seals	TM
9000-000-0019 (Eire)	Au-plated steel case, Ni-Fe terminals, P-Bronze washer, brass nut Glass seal	TC
IVB50 2VB65 05VB90 (Denesco)	Au-flash over Ni-plate over 1/4 hard Cu terminal and brass body Ag-plated spring steel, and brass Epoxy seal	TM
Transformers and Oscillators		
PT6-2062-67 (TRW Systems)	SN63 coated Cu stainless steel Bonded MT3-34	TC
D1-T265 (UTC)	Au-plated dumet paint; unidentifed epoxy	TM

7.2.3.4 Capacitors (Table 7-25)

Compatibility data were not found on the particular capacitors listed, but short exposure (24 to 36 hours) test data were available on many other capacitors, including liquid and solid tantalum, ceramic, paper, mica, and paper-Mylar. All except elastomerically-sealed tantalum capacitors were found to be unaffected by the exposure. The seals on the tantalum capacitors swelled and ruptured, and the component failed catastrophically (Reference 17).

Since these were short term exposures, and a failure was experienced, only glass-sealed capacitors are rated as tentatively compatible. All others are rated tentatively marginal.

Table 7-25. Components Compatibility Ratings—Capacitors

Component	Materials	ETO Compatibility Ratings
Potter/Khem-electro CER501 also AEROVOX, MC89	Hysol 427B cast epoxy preform Shell epoxy 828 resin with Union Carbide A186 Beta 3,4 catalyst	TM
Kg Series (Kemet) 350 D-Series (Sprague) CSR13 (Union (Carbide)	Tinned brass metal case, glass seal Heat shrinkable mylar sleeve	TC
CYFR (Corning glass)	Glass body Glass bead (proprietary) Au-plated leads	TC
160D Series (Sprague)	Solid Ta pellet Mylar sleeve Epoxy seal Unidentified paint Polyester tube	TM
GE16K (General Electric)	Stainless steel case Mylar sleeve GE glass seal	TC
127P Series (Sprague)	Glass seal Tinned brass case and Cu-weld leads	TC
D Series (Sangamo)	Epoxy dipped	TM

7.3 CONCLUSIONS

This investigation has shown that there should be no serious problems in material and component selection for ETO compatibility. Some areas have been noted where care must be exercised in making selections, but it is felt that adequate choices can be made.

Additional test data is needed on many materials and components. Also, much of the available data were obtained on exposures less severe than thought required to adequately qualify an item. Many items, particularly components, will have to be tested to conclusively determine their compatibility with ETO.

It is not imperative that only materials and components that show no degradation whatsoever be used on the Voyager. In some cases, materials whose compatibility with ETO is marginal can be considered for use. The degree of degradation of such materials must be such that the item can be shown to function reliably in the capacity for which it was chosen. Qualification of such marginal materials must include consideration of which properties the device must retain to function properly, the amount of surface area to be exposed, and the type and rate of degradation (i.e., if the ETO is merely absorbed during exposure, the properties may return following vacuum exposure.)

In cases where a marginal material is deemed unsuitable for a particular application, or where the chosen material is known to be incompatible, another material will have to be substituted for it. Some replacements have already been suggested in this report (e.g., Kynar to replace teflon or polyolefin). Each material suggested for a substitution will in turn have to be qualified for that particular use. If it is impossible to find a suitable substitute material, the incompatible material will have to be sealed off to prevent exposure to the gas. This has already been done in the case of some lubricants, photographic film, magnetic tape, and the bipropellants. Special care must be taken to ensure that the seals used to isolate incompatible materials are completely effective.

Some elastomeric seals are incompatible with ETO, consequently are unsuitable for sealing off other materials. Also, some silicone rubbers are partially permeable to ETO. Their applicability will depend on their thickness, size, and premeability to the gas. Glass-to-metal and metal-to-metal seals may be better for ensuring complete isolation of the incompatible material.

8. FACILITY REQUIREMENTS

The philosophy for contamination control and ETO surface decontamination operations are stated in the Contamination Control Plan, Section 6. Requirements for contamination control including the employment of ethylene oxide-Freon 12(ETO)as a surface decontaminant imposes specialized facility requirements in the manufacturing and launch areas. The area facilities have certain common requirements established by the basic ETO exposure methodology, as well as unique characteristics to satisfy operational and functional requirements of the specific area.

8.1 MANUFACTURING AREA

Specialized facilities imposed by ETO are required for contamination control, engineering evaluation, and qualification and acceptance testing of units and the completed spacecraft.

Contamination control is needed throughout manufacturing operations to limit the biological load on the spacecraft.

ETO engineering evaluation requirements cover a broad spectrum of activities, primarily of an investigative or developmental nature. Evaluation of components and materials to determine ETO compatibility is required. In addition, aspects of the ETO decontamination process must be evaluated. For example, the effectiveness of the ETO exposure may be affected by the surface conditions of the test item, as well as by temperature and relative humidity of the sterilant gas. Engineering investigations are required to show the effects of

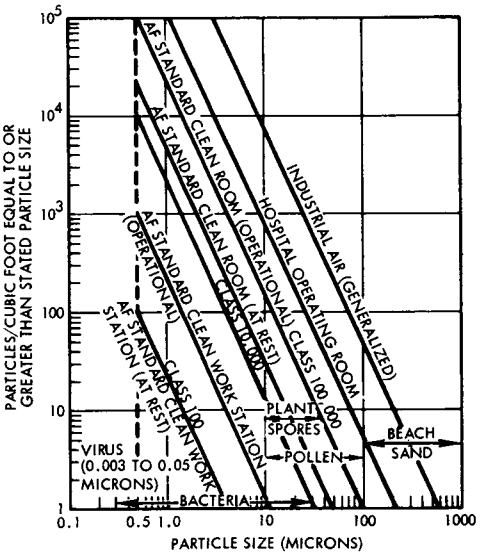
- Various cleaning methods
- Post-cleaning handling
- Different ETO exposure parameters.

Qualification and acceptance testing of units and spacecraft for ETO compatibility is required to determine the effects of the ETO sterilant gas. These exposures are intended to determine and verify the effects of the ETO decontamination process on the functional and operational

performance of the spacecraft and its components. As a part of the spacecraft integrated test program, these ETO cycles provide a verification of design and manufacturing techniques in terms of ETO compatibility.

8.1.1 Clean Room Requirements for Assembly, Integration, and Test

Use of FED-STD-209 class 10,000 facilities are indicated for all spacecraft operations from assembly through terminal decontamination (Section 4). Particulate characteristics of this class of facility are shown in Figure 8-1. It is compared with other classes of standard clean rooms. Basic design requirements for the facilities are established in the clean room specification (FED-STD-209).



PARTICLE SIZE DISTRIBUTION CURVES CLASS 100, CLASS 10,000, AND CLASS 100,000 ARE BASED ON FEDERAL STANDARD NUMBER 209

AIR FORCE STANDARDS ARE BASED ON 1 JULY 1963 ISSUE OF T.O. 00-25-203.

IN GENERAL, ITEMS THAT HAVE CLEARANCES LESS THAN 100 MILLIONTHS (2.5 MICRONS) INCHES REQUIRE THE USE OF A CLEAN WORK STATION.

HARDWARE THAT HAS CLEARANCES IN THE RANGE FROM 100 TO 1000 MILLIONTHS OF AN INCH OR IS AFFECTED BY PARTICLE SIZES FROM 2.5 TO 25 MICRONS SHOULD BE PROCESSED IN AN AIR FORCE STANDARD CLEAN ROOM OR BETTER.

ITEMS WITH APPROXIMATELY 500 MILLIONTHS OF AN INCH CLEARANCES MAY BE PROCESSED IN AN AREA SIMILAR TO A HOSPITAL OPERATING ROOM.

Figure 8-1
COMPARISON AMONG CLASSES OF CLEAN ROOMS and clean room stations.

The selection of a class 10,000 clean room was based upon engineering judgment since this method of control appears to provide adequate assurance that a minimum biological load will accumulate during the spacecraft assembly, integration, and test operations.

A class 10,000 clean room requires a locker room where garment changes are performed, and an air lock. Air showers are provided to blow off loose particles from the clothing prior to clean room entry. This change room must be maintained to the same cleanliness level as the clean room itself, with a positive pressure to assure that no outside air enters when the door is opened. The clean room also has a positive pressure,

higher than the air lock to assure that air from the lock does not enter the clean room. Generally, a differential of 0.05 to 0.15 inches of water is specified, assuming adequate seals at openings and construction joints. Higher differentials result in problems of opening and closing entry and exit doors.

Materials used in construction of clean rooms must be selected for minimum deterioration and abrasion, which would lead to particulate formation. Design and methods of construction must provide surfaces free of crevices, pits, openings, porosity, etc., by which contaminating material can enter or be retained. Flooring should be used which possesses long life and resistance to breakdown. Vinyl is well adapted to clean room usage. Thorough cleaning throughout the construction phase also is required.

As important as the clean room facility is, personnel control in clean room operations is also necessary because levels of microbiological contamination are influenced by the degree of activity of the occupant. Operational rules to be applied for work in such a room are as follows:

- Equipment must be cleaned before entry by vacuum, washing, or other suitable means
- No smoking or eating permitted
- Lint-free smocks required
- Complete head and shoe covering required
- Limit paperwork in room and use special nonshedding paper for necessary paperwork
- Lead pencils and erasers prohibited, use only ballpoint pens for writing
- Use hand lotions, creams to tighten skin particles as appropriate (do not use silicone-base hand lotions)
- Avoid solvent contact with hands
- Fingernail polish, large use of cosmetics, or medication not allowed
- Exhaust systems required for grinding and related operations.

Location of test and checkout equipment outside of the clean test area is indicated, wherever possible, to limit the number of personnel and equipment in the area. This allows better maintenance of the clean room, and avoids the need for equipment designs which meet contamination control standards. Electrical feedthroughs can be made from the "dirty" equipment area to the clean room. A viewing window between the two areas allows the equipment operator visual contact with the clean room.

8.1.2 ETO Evaluation and Test Area

In addition to class 10,000 clean rooms for assembly and test, areas will be required for ETO-material compatibility, unit qualification, and acceptance testing. These areas will contain ETO chambers discussed in Section 9. Only the ETO chambers for acceptance testing are installed in clean rooms.

The facility should contain provisions for ETO storage, distribution, and disposal. Efficient ventilation is also essential.

8.1.2.1 ETO Storage and Distribution

Liquid ETO (12 percent ethylene oxide, 88 percent Freon 12, by weight) may be purchased in a wide variety of container sizes. The major suppliers do not provide centralized storage and distribution facilities. However, these could be readily provided by the user in those locations where multiple chambers are in operation. For the environmental laboratory, where a significant volume of gas would be used, replaceable cylinders of approximately 1-ton net capacity will provide the most feasible means of storage. Small laboratory-type chambers, in which the use quantity is low, will be serviced by smaller portable containers associated with the individual chambers.

8.1.2.2 ETO Disposal

The disposal of the ETO sterilant gas at the end of the test cycle must be considered in the design of equipment and plant utilities. The chemical properties of ETO are such that proper methods of disposal must be utilized. The preferred method of disposal requires reaction

of the ethylene oxide with a dilute solution of hydrochloric acid. The products of this reaction would be various glycols, primarily ethylene glycol, and ethylene chlorohydrin, which can be safely discarded. This can be a batch process in which the efflux from the reaction vessel is stored, and then diluted before discharge into the drain. This disposal method requires an external atmospheric vent for the halocarbon gas (Figure 8-2).

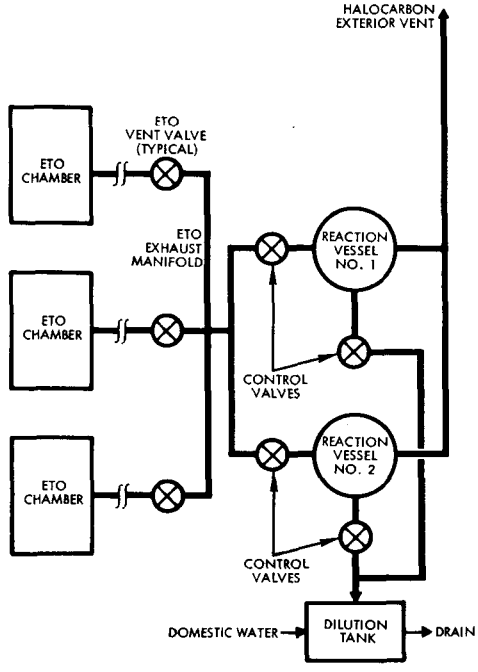


FIGURE 8-2
ONE METHOD OF ETO DISPOSAL employs dual reaction vessels containing dilute HCl. ETO reacts to form glycols which are washed to drain, while the halocarbon diluent is vented to atmosphere.

8.1.3 Biological Assay Facilities

A microbiological laboratory is needed as part of the engineering facilities to develop spacecraft biological assay methods and evaluate cleaning and decontamination procedures. The laboratory should contain the usual microbiology equipment such as microscopes, incubators and steam sterilizers. In addition, an ETO decontamination chamber, ETO glove box, and cleaning equipment will be needed.

Microbiological laboratories are also required close to assembly areas for quick processing of assay specimens. One laboratory should be sufficient for each facility complex. Assay specimens

include particulate and biological contamination samples from selected areas of the spacecraft and clean room air samples. Monitoring will be accomplished on a regularly scheduled basis, to assure maintenance of required contamination control conditions.

Investigations were made of air and surface biological assay methods to determine equipment requirements for these labs. They are discussed in Section 9.

8.2 LAUNCH SITE

8.2.1 Spacecraft Operations Area

The spacecraft operations area at the launch site (Kennedy Space Center) should be designed to incorporate FED-STD-209 class 10,000 clean room standards for spacecraft operations including receiving inspection, prelaunch checkout, cleaning, module or unit storage, replacement activities, and other activities noted in Section 6. The clean room requirements are identical to those specified for the manufacturing area.

A bonded store area for spare modules or units necessary as replacement parts is also operated under FED-STD-209 class 10,000 clean room conditions.

The high bay area in which spacecraft support operations are conducted should be of a minimum size to lessen the cost of construction. Checkout equipment, where possible, is mounted in an adjacent room (Figure 8-3). The clean room incorporates provisions for personnel dressing and preparation prior to entering the clean room and includes air washes, foot cleaners, and other standard clean room devices. In addition, provisions must be made for power and other services required to operate the spacecraft during prelaunch operations. Adequate lighting must be provided with an average table-top power level of 500-foot candles. The schematic floor plan arrangement, shown in Figure 8-3, indicates the requirements for receiving inspection, spacecraft checkout, spacecraft storage, bonded storage, checkout equipment, and personnel access areas. This facility is designed to simultaneously accommodate three spacecraft during prelaunch operations. General overall size

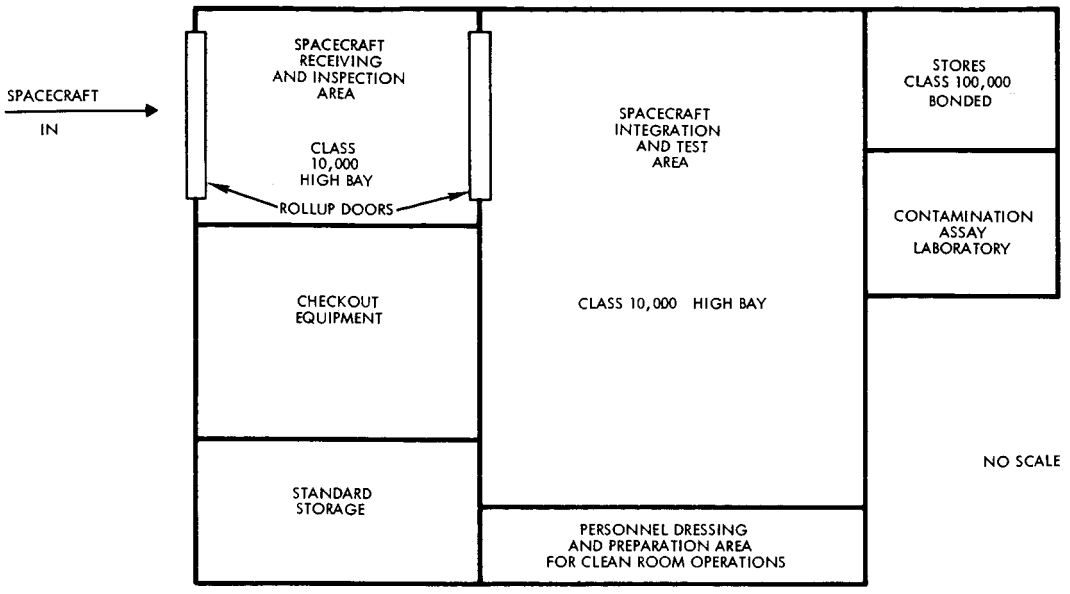


Figure 8-3
SCHEMATIC FOR LAUNCH SITE SPACECRAFT OPERATIONS area within PVIAT is shown.

requirements and square footage requirements may be generated and applied to modification of existing buildings at the launch site, or to a new facility, as appropriate.

The design and construction of the clean rooms is similar to those utilized during manufacturing operations. The facility will be designed to enable regularly scheduled maintenance for filter replacement, lighting replacement, etc. Periodic monitoring of air flow using a velometer enables a determination of the filter replacement cycle.

8.2.2 Planetary Vehicle Operations Area

Facilities in which planetary vehicle operations are conducted to maintain contamination control of the spacecraft, capsule, planetary vehicle, planetary vehicle compartment, and associated equipment are illustrated in the schematic layout, Figure 8-4. Clean room and other facility requirements are identical to those requirements stated for the spacecraft area.

8.2.3 ETO Decontamination Facility

Terminal ETO decontamination may be conducted utilizing several basic methods. The methods and facility requirements for each are described below.

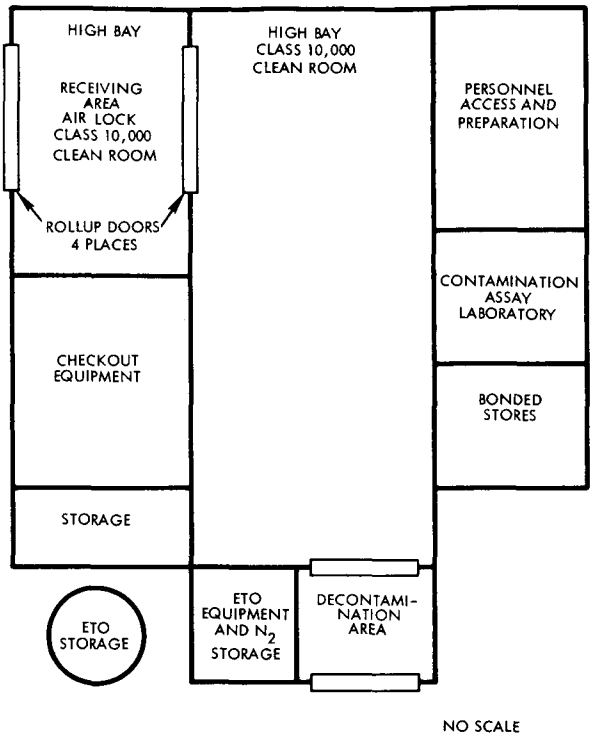


Figure 8-4
SCHEMATICS FOR LAUNCH SITE PLANETARY VEHICLE OPERATIONS AREA within PVIAT is shown.

8.2.3.1 ETO Decontamination Room

ETO decontamination may be conducted within the planetary vehicle operations area in an enclosed room, shown in Figure 8-4. The planetary vehicle compartment is brought to an adjoining bay to be cleaned, and final preparation for ETO operations is completed. Decontamination is performed by connecting the ETO unit directly to the planetary vehicle compartment and filling the compartment by displacement. At the conclusion of the cycle, ETO is removed from the planetary vehicle compartment by flushing with sterile nitrogen.

The room should be sealed for ETO decontamination operations, to provide adequate safety precautions. Also, adequate ventilation to the outside atmosphere must be provided from the ETO room to dissipate fumes in case of leakage during operations. Monitoring instrumentation should be installed in the area to detect ETO vapors. Since ETO is heavier than air, excessive concentrations can accumulate at the floor level. The room must be designed to incorporate emergency measures, when excess vapors are detected, to dissipate the vapor in a safe manner.

8.2.3.2 ETO Vacuum Chamber

Another mode of ETO decontamination operations being considered utilizes a vacuum to evacuate the planetary vehicle compartment prior to commencement of the terminal ETO decontamination cycle, and immediately after the ETO cycle prior to purge operations. This will expedite the ETO cycle time span, and the ETO gas will be more readily and positively removed at the conclusion of the cycle. If terminal ETO operations are to be conducted in the planetary vehicle area, a chamber must be constructed such that a vacuum is pulled on the entire planetary vehicle compartment. This chamber will relieve loads on the planetary vehicle compartment structure, which is limited to a maximum of 5 psig. It should be a steel cylinder capable of enclosing the encapsulated planetary vehicle and designed to maintain vacuum conditions. Other requirements for the chamber are facility vacuum roughing pumps, and a removable cover to aid in installing and removing the planetary vehicle assembly. Safety requirements such as explosion-proof electrical lines, ventilation, and lighting, should be incorporated.

8.2.3.3 Existing Kennedy Space Center Vacuum Chamber

A third mode of ETO operations is identical to that described in Section 8.2.3.2 but utilizes the existing thermal vacuum chambers located in the MSOB at Kennedy Space Center, shown in Figure 8-5 and presently required for the Apollo Program. Initial investigations indicate that these two chambers are of sufficient internal capacity to enable terminal ETO operations to be conducted. Safety restrictions in the MSOB negate fueling the planetary vehicle prior to ETO operations. Modifications may be required to provide proper crane hook height clearance, since at the present time inadequate clearance may exist. An additional 10 feet of clearance may be required, although additional study will be necessary to establish a final dimensional requirement. If safety waivers to consider a fully fueled planetary vehicle cannot be obtained, planetary vehicle fueling operations must be conducted after the terminal ETO decontamination, resulting in an impact on the design of the planetary vehicle/planetary vehicle compartment interface area (such as umbilical lines from the exterior of the shroud to the planetary vehicle tank section).

The third mode of operation appears least desirable at this time. It may be seen that ETO requirements impose the greatest impact upon the planetary vehicle operations facilities in terms of building space.

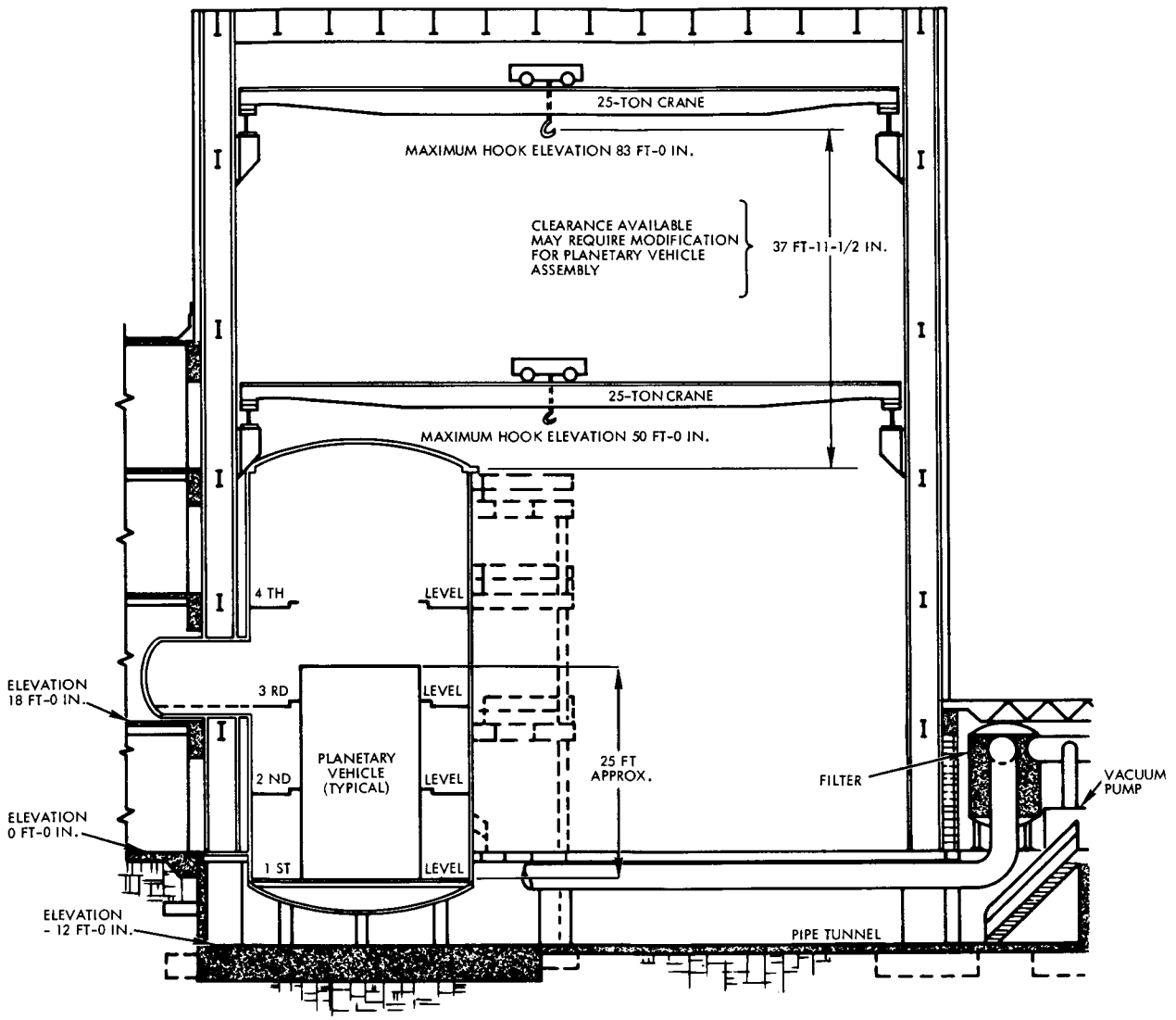


Figure 8-5
EXISTING KSC APOLLO PROGRAM VACUUM CHAMBER has been investigated for use in Voyager ETO decontamination operations.

8.2.4 Launch Pad Facility

Facility requirements to meet contamination control standards at Kennedy Space Center launch complex 39 appear to be minor at this time. It is desirable to provide a capability for cleaning the exterior of the planetary vehicle shroud prior to liftoff to reduce the possibility of exterior particulate contamination transferring to the spacecraft during planetary vehicle separation after orbital injection. These provisions may consist of an air wash system, vacuum cleaning system, or water or other liquid wash system. Additional study will be needed to establish firm requirements for cleaning of the shroud exterior.

Provisions will be necessary to accommodate two special aseptic ground cooling units — one for each planetary vehicle. These units supply filtered dry nitrogen coolant to the interior of the planetary vehicle compartment after terminal decontamination. They are needed to remove excess heat generated by the on-board electronic systems during checkout operations. During launch pad operations, the coolant units may be installed at the base of the launch pad, or within the umbilical tower at the level of the planetary vehicles, and connected through the umbilical mast located on the launch platform. The coolant umbilical will remain connected to each planetary vehicle until liftoff.

8.3 SAFETY

8.3.1 Manufacturing Area

The use of ETO in an enclosed laboratory requires the continuous monitoring of the concentration of the gas in order to ensure personnel safety. The most commonly specified toxic threshold is 50 parts per million. This requirement is easily met by installation of a nondispersive infrared gas analyzer in each laboratory area, which is equipped with a continuous recorder and an appropriate alarm system (Figure 8-6). Other safety requirements imposed by contamination control, discussed previously, include adequate ventilation and ETO disposal.

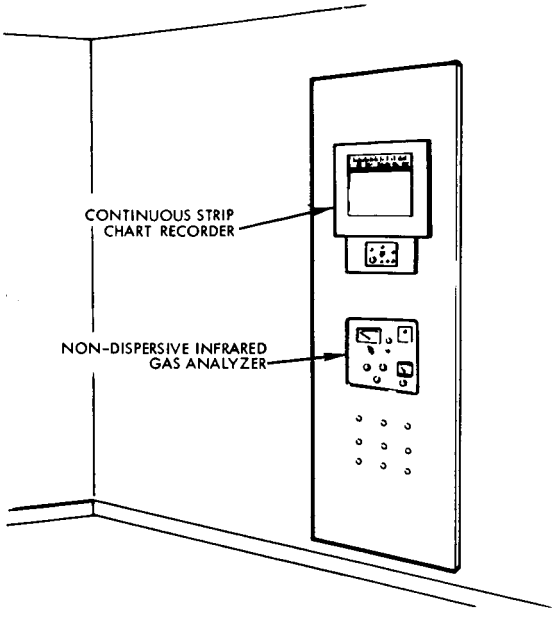


Figure 8-6
SAFETY MONITOR, for ethylene oxide concentration provides alarm when toxic threshold (50 ppm) is exceeded.

8.3.2 Launch Site

8.3.2.1 Spacecraft Operations Area

No specialized safety requirements related to decontamination requirements in spacecraft operations can be identified at this time, since only particulate contamination control operations will be accomplished in this area.

8.3.2.2 Planetary Vehicle Operations Area

Planetary vehicle operations area safety requirements will be based upon the requirement to perform the terminal ETO decontamination cycle within this area.

The terminal ETO decontamination area may be a portion of the overall facility or be physically removed some distance, based upon which mode of operation, described in Section 8.2.3, is finally selected. Safety requirements for other operations are discussed in the spacecraft operational sequence and are not a portion of the contamination control requirements. Safety provisions for ETO operations include sensors which will shut off the gas supply when excess ethylene oxide gas is sensed, and trigger a Freon 12 or nitrogen gas purge system to allow

the escaping ETO gas to be neutralized, since ethylene oxide without proper dilution is highly toxic. These precautions are mandatory.

8.3.2.3 Launch Pad

No specific safety provisions to accommodate contamination control at the launch pad are necessary, since no ETO operations are anticipated at this time.

9. EQUIPMENT REQUIREMENTS

Specialized equipment will be required to implement contamination control procedures at the manufacturing area and launch site. This equipment will be utilized for testing, monitoring, cleaning, and ETO decontamination operations. This equipment is described in detail below.

9.1 MANUFACTURING AREA

9.1.1 ETO Test Chambers

The majority of existing ETO test chambers are patterned structurally and operationally similar to steam autoclaves. This is due to primary usage in the medical and pharmaceutical disciplines. Many requirements imposed by dry heat or steam sterilization are not necessary for ETO exposure, nor are they appropriate. In addition, existing ETO chambers have only been modified to incorporate the admission of sterilant gas and humidity, and to include a more accurate temperature control system. The more stringent ETO chamber design requirements imposed by ETO decontamination of spacecraft components cannot reasonably be satisfied by this existing equipment. ETO chambers more appropriate to the task should be patterned after temperature or temperature/altitude chambers which use conventional gasketed door closures, circulation fans, higher quality instrument and control functions, a lightweight stainless steel inner liner, and a separate control console. ETO chambers which have been specifically designed and manufactured to meet Voyager specifications exist at several locations in this country (including the Sterilization Assembly Development Laboratory at JPL and also at NASA, Goddard). These chambers are in various stages of construction and operation and are of several different designs. Prior to the actual procurement of such equipment, a thorough survey of these chambers will be conducted in order to assess the operational suitability of the various designs. Design considerations include physical cleanliness, exposure volume, ease of operation, and accuracy and reproducibility of the test exposure. The last design consideration implies a complete evaluation of the instrumentation methods, for example, relative humidity and ETO partial pressure measurements.

9. 1. 1. 1 Material and Component ETO Test Chambers

ETO test chambers required by engineering personnel for material and component ETO compatibility test and evaluation will employ sound human engineering design to allow simple straight-forward operation. It is essential that this equipment be capable of controlling each of the ETO exposure parameters, such as temperature, humidity, flow rates, and exposure time, over a considerable range. This will allow assessment of the effects of parameter variation. These features primarily affect the instrumentation and control functions and are described in Section 9. 1. 1. 4. The size of the compatibility test chambers is established in terms of operational convenience. A chamber having an exposure volume of 8 cu ft will satisfy most engineering requirements. This size is not dictated by acquisition costs, but by the use of smaller quantities of sterilant gas required. This simplifies the disposal, instrumentation, and control functions.

9. 1. 1. 2 Unit Qualification and Acceptance Chambers

The manner in which the unit qualification and acceptance test chambers will be utilized requires that they be designed for convenient automatic cycling of a predetermined ETO exposure profile. Each phase of the ETO decontamination cycle will be programmed in terms of time duration as well as the achievement of specific values of test parameters. The physical size of the chamber is established by operational convenience as well as by the size and quantities of the units being tested. The chamber is illustrated in Figure 9-1. In unit qualification and acceptance testing, it is convenient to employ multiple testing of units since the unit under test is not required to operate during the ETO exposure cycle, and no unit functional support equipment is required. Experience in the operation of temperature, altitude, and vacuum test chambers indicates that a test volume of 64 cu ft is convenient to use and provides a reasonable degree of operational flexibility. These chambers will be free standing and similar to the design configuration of existing temperature and vacuum chambers. The size selected above will allow convenient use of loading carts and handling trays and will minimize physical contact with the unit to be tested.

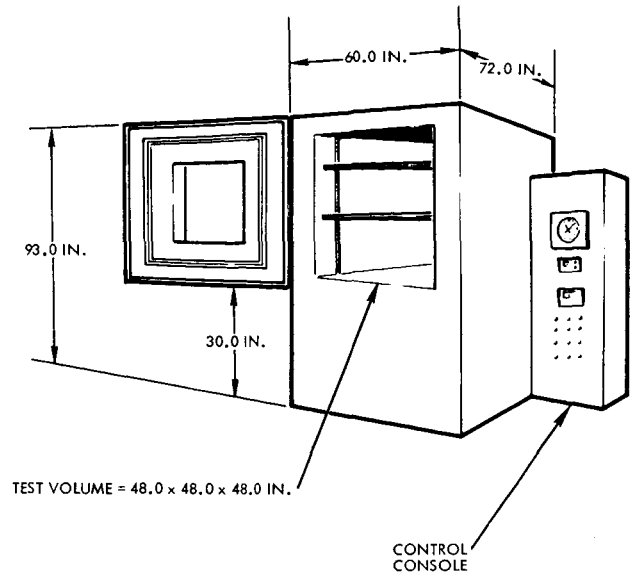


Figure 9-1

ETO TEST CHAMBER is patterned after typical temperature-altitude chamber. Evacuation, gas control and temperature conditioning are controlled by adjacent console.

9. 1. 1. 3 Spacecraft Qualification Chambers

The exposure of the complete spacecraft, to establish operational compatibility of the ETO decontamination cycle, will employ the same mobile ETO decontamination unit utilized at the launch site (described in Section 9. 2. 1). The spacecraft will be enclosed in a mockup or test article planetary vehicle compartment during the ETO cycle and placed in an airtight enclosed ETO test area.

9. 1. 1. 4 ETO Chamber Instrumentation and Control

The most important design characteristics of the ETO exposure chamber are in the area of instrumentation and control. A functional diagram of the instrumentation and control requirements is shown in Figure 9-2. The instruments and control functions must have sufficient accuracy to enable control of the specified ETO parameters within reasonable tolerances. The principle ETO test parameters which require accurate control and regulation are

a) Temperature

b) Pressure

c) Time

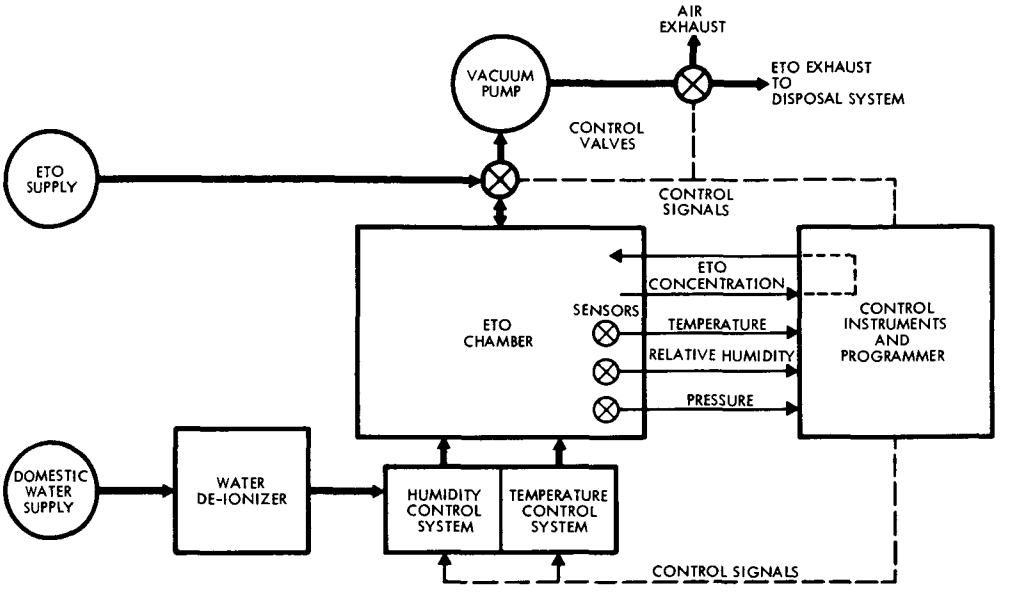


Figure 9-2
ETO CHAMBER INSTRUMENTATION utilizes high-quality control instruments to provide accurate and reproducible exposure parameters.

d) Relative humidity (H_2O partial pressure)

e) Ethylene oxide concentration.

Temperature, Pressure, and Time Regulation and Control. The measurement of temperature, pressure, and time can readily be achieved with existing conventional high quality instruments. The control of these three parameters, with the possible exception of temperature, is straight forward from a design standpoint. In an ETO chamber it is essential to avoid localized hot areas which would be contacted by the ETO sterilant gas, in order to reduce the possibility of ethylene oxide polymerization or decomposition.* This may require the employment of extended-surface heat exchangers rather than conventional heaters.

Relative Humidity Control. The measurement and control of relative humidity can be accomplished by using a nondispersive infrared gas analyzer.

The nondispersive infrared gas analyzer measures the concentration of one specific gas for which it has been characterized. This is accom-

*Ethylene oxide decomposes at ~780°F. Polymerization can occur as low as 200°F if a catalyst is available.

plished by measurement of the relative absorption of infrared radiation as it is transmitted through the test sample. The degree of absorption of the test sample is compared with that of a reference sample. The advantage of this analyzer is that it provides a continuous indication of gas concentration and can readily be incorporated into a conventional control circuit. This capability is of particular importance for ETO chambers being used in engineering evaluation tests where controlled variation of the test parameters is a requirement.

Wet bulb depression sensors are not suitable due to the high solubility of ETO in water within the temperature range of the ETO test exposures. A number of conductivity type cells have been evaluated for this purpose, but most have proven unsatisfactory. A possible exception may be a styrene polymer sensor, whose surface conductivity is related to moisture concentration. Preliminary tests of this type sensor have indicated that the sensor degrades slowly with exposure to ETO. This would require frequent replacement.

Ethylene Oxide Concentration Measurement. The concentration of pure ethylene oxide in the ETO sterilant gas is initially established by the relative quantities of ethylene oxide and halocarbon (Freon) which are introduced to the chamber, or as it comes from the storage cylinder. The effects of differential absorption of the two gases during the ETO cycle may change the concentration of ethylene oxide. Therefore, concentration measurements are also needed during the cycle. The most promising methods of determining ethylene oxide concentration utilizes a gas chromatograph or a nondispersive infrared analyzer.

The principle of operation of the gas chromatograph instrument is the same as other transit-time instruments, wherein a volumetric sample of the test gas is passed through an exchange column, in which the relative thermal conductivity of the effluent is measured as a function of time. Since each gas has a characteristic transit time and conductivity, the identity and relative concentration of each species can be established. This characteristic is the major advantage of the chromatograph since all gases are identified simultaneously. The major disadvantage is the lack of a continuous indication of the concentration of a specific component. Therefore, it is difficult to incorporate this type of instrument into a closed-loop control system.

9.1.1.5 ETO Chamber Procurement

A number of ETO sterilization chambers have been supplied by manufacturers well versed in the area of medical sterilization requirements. Until recently, biological sterilization was accomplished almost exclusively by means of dry heat or steam sterilizers. The increased application of ETO for sterilization in spacecraft and other applications has prompted these manufacturers to provide the necessary equipment. Due to procurement cost limitations, ETO chambers are comprised primarily of modified autoclave equipment with added controls and conditioning functions for sterilant gas, temperature, and humidity. As indicated previously, tolerances on ETO exposure parameters for spacecraft applications will be more restrictive and require, in some cases, a different technical approach.

There has been limited engineering activity conducted by existing medical sterilizer manufacturers to provide more suitable chambers; however, the resultant hardware has not been produced in significant quantities. The major shortcoming of off-the-shelf ETO chambers is in the area of thermal transfer and instrumentation and control functions. The manufacturers of environmental test equipment, (such as vacuum, temperature, and humidity chambers) appear better equipped, from engineering and fabrication experience, to produce appropriate instrumentation and controls; but they have had little, if any, experience with the special requirements imposed by the use of ETO. Despite this negative factor, it appears that certain environmental equipment manufacturing firms would be the most suitable sources for ETO decontamination chamber procurement.

A complete procurement specification must be generated for each ETO chamber required for material and component testing and unit qualification. This is a desirable practice for any item of test equipment, but is particularly appropriate for ETO chambers due to the lack of first-hand experience possessed by the suitable suppliers. Table 9-1 provides an outline for an ETO chamber procurement specification.

Table 9-1. Procurement Specification Outline for ETO Decontamination Chamber*

1. Introduction
2. General Description
   - 2.1 Test Zone
   - 2.2 Chamber Configuration
3. Performance Requirements
   - 3.1 Temperature Range
   - 3.2 Relative Humidity Range
   - 3.3 Temperature Control
   - 3.4 Relative Humidity Control
   - 3.5 Heating and Cooling Rates
4. Instrumentation and Control
   - 4.1 Instrumentation Accuracy (Subparagraph for Temperature RH, Pressure, ETO Conc.)
   - 4.2 Control Method (Subparagraph for Temperature RH, Pressure, ETO Conc.)
   - 4.3 Control Accuracy (Subparagraph for Temperature RH, Pressure, ETO Conc.)
   - 4.4 Automatic Programming
5. Electrical System
   - 5.1 Wiring
   - 5.2 Labeling
   - 5.3 Terminal Boards
   - 5.4 Lacing
   - 5.5 Control Circuit
   - 5.6 Electrical Switching
   - 5.7 Overload Protection
   - 5.8 Control Compartment
   - 5.9 Test Zone
6. Construction Details
   - 6.1 General
   - 6.2 Access
   - 6.3 Door
   - 6.4 Test Zone
   - 6.5 Circulation
   - 6.6 Insulation
   - 6.7 Temperature Conditioning Functions
   - 6.8 Humidity Conditioning Functions
   - 6.9 Sterilant System
7. Safety Devices
   - 7.1 Temperature Control System
   - 7.2 Refrigeration System
   - 7.3 Fail Safe
   - 7.4 Humidity Control System
   - 7.5 Operational Interlocks
8. Utilities
   - 8.1 Electrical Supply
   - 8.2 Water
   - 8.3 Air
   - 8.4 Sterilant Gas Supply
   - 8.5 Sterilant Gas Disposal
9. Approval, Acceptance, and Delivery
   - 9.1 Design Approval
   - 9.2 Acceptance
   - 9.3 Delivery
10. Documentation
    - 10.1 Delivery Requirements
    - 10.2 Operating Manual
    - 10.3 Service Manual

*Covers all pertinent functional and operational requirements as well as chamber configuration.

9.1.1.6 ETO Test Chamber Quantities

The quantity of ETO chambers required for manufacturing operations outlined in Table 9-2 reflects an evaluation of the type of tests and exposures to be performed in each area discussed previously. The quantities are also a function of exposure test article quantities and exposure cycles.

Table 9-2. ETO Test Chamber and Related Equipment Requirements

Material and Component Evaluation

Description	Req.
ETO Chamber (8 cu ft)	3
Safety Monitor	1
ETO Disposal System	1
ETO Supply System	1

Unit Qualification and Acceptance

Description	Req.
ETO Chamber (64 cu ft)	2
Safety Monitor	1
ETO Disposal System	1
ETO Supply System	1
System Portable Supply	1

The chamber quantities shown in Table 9-2 for engineering evaluation of material and component ETO compatibility are based on the performance of approximately 1000 individual exposure cycles of 1-day duration, over a 2-year period. Smaller chambers are selected to provide convenience and economy of operation for the smaller test samples. In the event that a larger chamber is required for larger sample exposures, it is intended that the chambers in the qualification and acceptance test area be utilized, since the peak exposure requirements in the two areas will not be concurrent. Three chambers, having a usable test volume of 8 cu ft, will be sufficient.

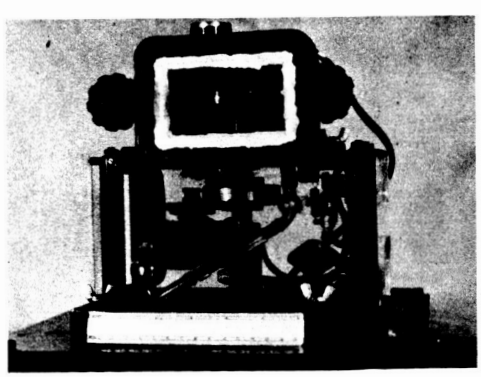
The ability to conveniently employ multiple-unit testing at the assembly level for qualification and acceptance testing indicates that two ETO chambers, each having a 64 cu ft test volume, will satisfy these requirements. A single semiportable ETO decontamination system will be used, in association with a suitable enclosure, for decontamination of larger items such as subsystems. The duration of the acceptance tests are discussed in the Contamination Control Plan, Section 6.

9.1.2 Biological Sampling Equipment

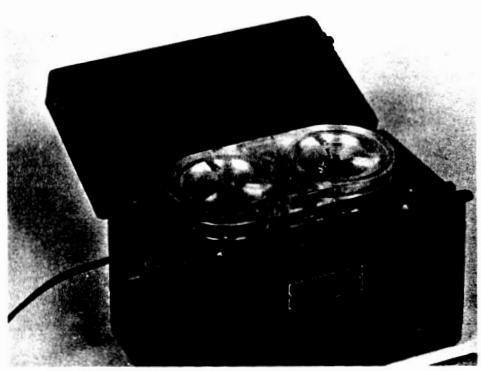
Assurance of contamination control during all spacecraft assembly, integration, and test operations is achieved through biological monitoring of selected parts, units, and areas of the spacecraft. Method of biological monitoring and associated equipment required are discussed below.

9.1.2.1 Air Sampling

Methods for sampling airborne bacteria are basically the same used to sample other airborne particles, except that the sampling method must not cause destruction of the microorganism. Methods include impingement in liquids, impaction on solid surfaces, filtration, sedimentation, centrifuge, electrostatic precipitation, and thermal precipitation. A U. S. Public Health monograph (Reference 27) describes sampling instruments that utilize these techniques. Liquid impingers and electrostatic precipitators appear most suitable. Characteristics of the various samplers are summarized below. Two of the samplers are shown in Figure 9-3.



Casella Slit Sampler



GE Electrostatic Precipitator

Figure 9-3
TWO TYPES OF BACTERIA SAMPLERS for spacecraft contamination control.

Liquid Impingement Samplers. This sampler requires the use of an antifoam agent, and is adapted to low concentrations. The size of air samples can be varied within wide limits, and sampling time is dependent upon rate of evaporation of the collecting liquid. Disintegration of particles can occur in various degrees. High efficiency for particles greater than 1 micron at high jet velocities can be obtained, but some killing effect is associated with high impingement velocities and extended continuous sampling. Quantitation is achieved by diluting and plating procedures. Final assay results are expressed as organisms per unit volume of air. This sampling method is generally limited to use at temperatures above 40°F, unless a heater or suitable antifreeze agent is used. The equipment is easily sterilized by autoclaving, is simple to operate, portable, but easily damaged.

Filtration Samplers. The usefulness of the filtration sampler depends upon the ability of the microorganisms to resist desiccation associated with filter collection. This method is suitable for collection of spores and other resistant microbial forms and has a high collection efficiency. Except for membrane filters, quantitation is achieved by washing and plating procedures. Some disintegration of particles can occur during washing. Final assay results are expressed as organisms per unit volume of air. The filtration sampler can be used at temperatures above and below freezing; it is simple to operate, portable, and all filter media is commercially available. All samplers can be sterilized by gas, but only a few can be autoclaved.

Sedimentation Samplers. Sedimentation samplers require a long sampling time for all particles to settle, and agglomeration of particles can occur during the settling process. This method is generally selective for large particles. Results can be affected by air currents and drafts. The equipment is simple to use, inexpensive, readily available, and easily sterilized by autoclaving. In utilizing this method the particles are randomly distributed over the collecting surfaces. Collection of viable particles on non-nutrient surfaces is limited to spores and other resistant microbial forms.

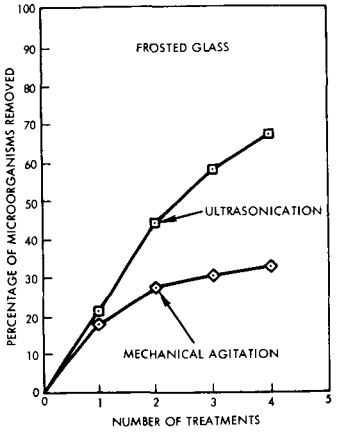
Centrifugal Samplers. Centrifugal samplers collect nondisintegrated or unmodified particles for microscopic examination or viable quantitation. The particles are not randomly distributed over the collecting surfaces. Collection of viable particles on non-nutrient surfaces is limited to spores and other resistant microbial forms. The efficiency of this method depends upon operating conditions and size of the particles to be samples. The sampling equipment can be sterilized by ETO gas.

Electrostatic Precipitator. The electrostatic precipitator collects nondisintegrated or unmodified particles for colony growth. No diluting or plating procedures are required, but this method is not well adapted to high concentrations. The final assay results are expressed as particles per unit volume of air. This method has a high sampling rate and collection efficiency, and low resistance to airflow. The equipment is complex and requires careful handling. It can be sterilized by ETO gas and is commercially available.

Thermal Precipitator. The thermal precipitator collects nondisintegrated particles for microscopic counting and sizing. Size distribution of particles can be determined from the data. This method is limited to low concentrations if particles are to be counted and is not generally used for quantitation of viable particles. The method has a high collection efficiency for small particles (less than 5 microns), but a low sampling rate. It is complex and requires careful handling and adjustment. The equipment can be sterilized by ETO gas and is commercially available.

9.1.2.2 Surface Sampling

Small Parts. A desired method to assay surface contamination on small parts is to immerse the entire part in a liquid (saline water, peptone water, or distilled water) and agitate to remove the microorganisms. Portions of the liquid containing the dispersed microorganisms is cultured and counts conducted on microbial colonies formed. Ultrasonic tanks are required to utilize this method of assay to provide the agitation for removal of viable particles. Puleo, Favero and Tritz have demonstrated that this method of removal is superior to mechanical agitation (Reference 28). Results of these tests are shown in Figure 9-4.



SURFACE	PERCENTAGE OF MICROBIAL CONTAMINANTS RECOVERED AFTER EACH TREATMENT							
	ULTRASONICATION				MECHANICAL AGITATION			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
SMOOTH GLASS	86[1]	88	91	96	80	81	87	95
STAINLESS STEEL	87	93	95	97	90	93	94	95
FROSTED GLASS	77	83	85	94	77	80	84	84
ELECTRONIC COMPONENT	86	88	91	92	71	80	90	96

[1] EACH VALUE IS THE AVERAGE OF FIVE DETERMINATIONS.

Figure 9-4
ULTRASONICATION is more efficient than mechanical agitation in removing microbial contaminations from surfaces.

Large Parts. Current methods for assaying large parts include swabbing and attaching metal coupons to the part which are exposed to the same environment as the part. The coupons are removed and assayed in the same manner as for small parts. The swab method is inefficient, allowing only about 70 percent recovery of microorganisms. The metal coupon method is awkward and can be impractical on some parts.

A vacuum probe surface sampler, which promises to overcome the difficulties noted above is now under development (Reference 29). The equipment, shown in Figure 9-5, consists of a small pencil-shaped vacuum probe attached to a slit sampler or a membrane filter apparatus. The probe is passed over an outlined area to be sampled. Viable particles are picked up and impacted on an agar plate in the slit sampler or on the membrane filter. The filter is placed on an agar plate. The plate is incubated and the colonies that form are counted. Critical air flow for efficient pickup by the probe is 1.5 to 2 cu. ft/min. This is achieved more easily with the membrane filter apparatus than with the slit sampler. The method is applicable only for collecting spores, since many vegetative micro-organisms are destroyed by desication or

impaction on the membrane filter. The efficiency of this probe design is illustrated in the summary on long-term testing, Table 9-3 (Reference 30).

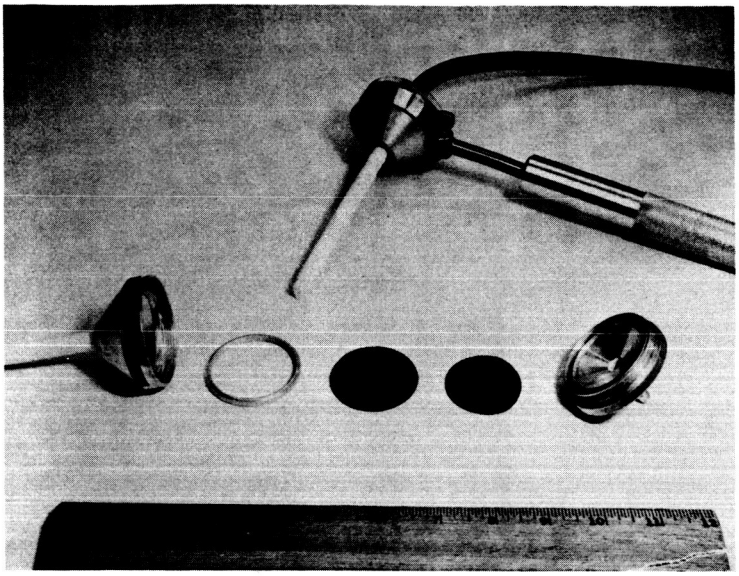


Figure 9-5A
THE VACUUM PROBE SURFACE SAMPLER removes microorganism from spacecraft hardware to assay contamination level.

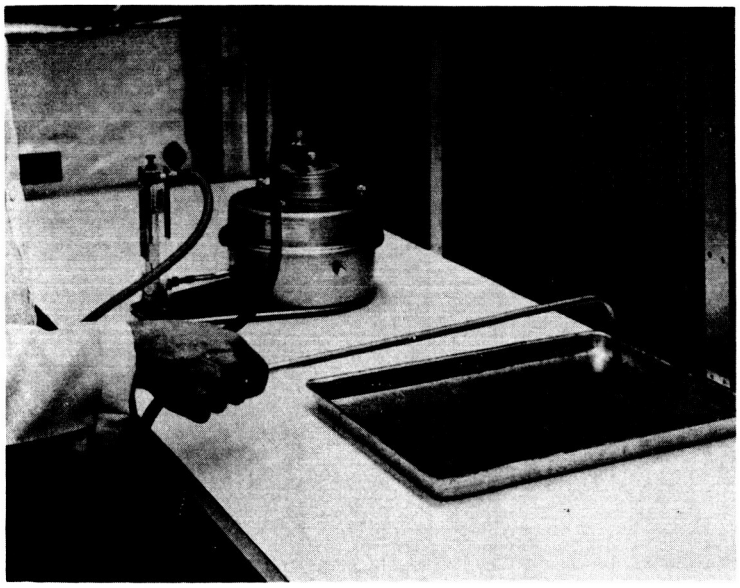


Figure 9-5B
THE VACUUM PROBE SURFACE SAMPLER is connected to a slit sampler for collection of viable microorganisms removed from surface of the pan.

9.1.2.3 Summary of Required Biological Monitoring Equipment

Microbiological monitoring equipment requirements include ultrasonic scrubbing tanks for whole part sampling and air and surface samplers. The most desirable air and surface samplers appear to be liquid impingers, electrostatic air samplers, and vacuum probe surface samplers.

Table 9-3. Results of Studies on Vacuum Probe Sampling Efficiency

Long Term Studies Conducted With Artificially Contaminated Surfaces

Period of Environmental Exposure (Days)	Colonies on Vacuumed Half of Pan	Colonies on Unvacuumed Half of Pan	Probe Removal Efficiency (%)
Zero	129	1115	88.4
29	114*	816	86.0
60	52	751	93.1
92	64	728	91.2

Long Term Studies Conducted With Naturally Contaminated Surfaces

Period of Exposure	Colonies on Vacuumed Half of Pan	Colonies on Unvacuumed Half of Pan	Membrane Filter	Probe Removal Efficiency (%)
Ambient-15 Days	15	338	624	96
Ambient-31 Days Covered- 5 Days	26	359	808	93
Ambient-31 Days 33% RH - 5 Days	19	352	831	95
Ambient-31 Days 75% RH - 5 Days	18	238	157	92

*Reyniers Samplers in-line contained faulty gaskets that failed to seal sampler tightly.

9.1.3 Clean Benches

Clean benches or work stations can be used in the manufacturing areas for unit or assembly level operations to correct faulty equipment or for calibration and adjustments. The clean bench illustrated in Figure 9-6 is typical of benches that may be utilized in unit assembly and test areas, as well as in the spacecraft assembly area.

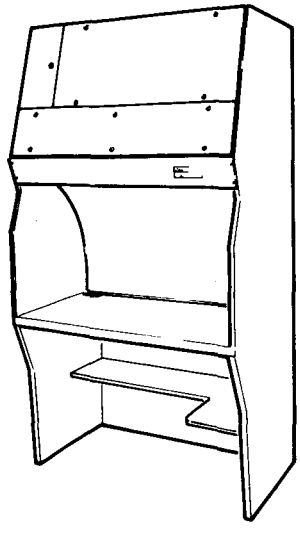


Figure 9-6
TYPICAL CLEAN WORK STATION for subsystem or unit assembly, repair, and checkout operations utilizes 90° converging laminar flow design principle.

9.1.4 Cleaning Equipment

Equipment is needed for piece part, unit, spacecraft, and checkout equipment cleaning. Ultrasonic tanks and vapor degreasers can be used for cleaning small items, and vacuum cleaners can be used for large assemblies. Studies of washing techniques show that ultrasonic scrubbing followed by vapor degreasing is very effective in removing microbiological contamination. Integrated units incorporating both ultrasonic tanks and vapor degreasers are commercially available, and should be suitable for this task. Vacuum cleaners are necessary in the work areas to clean the spacecraft and the checkout equipment on a periodic basis. A central vacuum system located in each major spacecraft operations area would be appropriate for this task.

9.2 LAUNCH SITE

The following specialized equipment is necessary to conduct prelaunch operations and to assure continuous control of the biological and particulate contamination level of the spacecraft.

9.2.1 ETO Decontamination Unit

A mobile ETO decontamination unit is required to conduct terminal ETO decontamination operations for the three encapsulated planetary vehicles at the launch site. This unit may be located in the vicinity of the planetary vehicle operations area or at another location selected for the terminal ETO decontamination operations. The ETO decontamination unit functional requirements are as follows:

1) To supply dry nitrogen gas to the encapsulated planetary vehicle at a temperature of $90^{\circ} \pm 5^{\circ}F$ and a pressure of 0.5 psig. This gas is required to preheat the planetary vehicle assembly to a stabilized temperature of $86^{\circ}F$ prior to initiation of ETO flow.

2) To supply ETO gas to the planetary vehicle compartment at a temperature of $86^{\circ}F$ to $95^{\circ}F$, a pressure of 0.5 psig, and a relative humidity of 40 ± 5 percent.

3) To circulate and replenish ETO gas through the planetary vehicle compartment for a period of 11 to 18 hours, maintaining the prescribed gas temperature,

pressure, and relative humidity. The precise length of the ETO cycle will be determined from an assay of the biological load of the planetary vehicle, prior to commencement of ETO operations.

4) To safely dispose of ETO gas after completion of the ETO cycle.

5) To supply and circulate sterilized dry nitrogen purge gas at a temperature of 90° ±5°F to purge the planetary vehicle compartment of ETO after the decontamination cycle has been completed.

Based upon the functional requirements noted above, the design requirements for the decontamination unit are as follows:

1) To supply a liquid ETO mixture from on-board storage tanks or from a centralized facility storage tank. Approximately 9000 pounds of liquid will be required for each complete decontamination cycle.

2) To vaporize and temperature-condition the ETO to the proper values (86° to 95°F) in order to maintain internal ambient conditions within the planetary vehicle compartment during the ETO decontamination cycle.

3) To inject water vapor to provide the desired ETO gas humidity of 40 ±5 percent.

4) To circulate the ETO gas through the planetary vehicle compartment, maintaining a positive internal pressure of 0.5 psig, and providing a flow rate of approximately 18 cu ft/min.

5) To safely dispose of the ETO gas at the conclusion of the decontamination cycle by reduction of the ethylene oxide to a nonhazardous compound.

6) To supply approximately 200,000 cu ft of preheated nitrogen gas for each decontamination cycle, utilizing either on-board storage tanks or a centralized facility storage supply.

7) To supply an estimated 49,000 cu ft of nitrogen purge gas for each decontamination cycle, utilizing on-board supply tanks or a centralized facility for storage.

8) To sterilize, temperature-condition, and dehumidify the purge gas to a temperature of 90° to 95°F and a relative humidity of 15 ±5 percent.

9) To circulate the purge and preheated nitrogen gas through the planetary vehicle compartment at a flow rate of approximately 420 cu ft/min, maintaining a positive internal pressure of 0.5 psig.

10) To provide monitoring and positive control of ETO and nitrogen preheat and purge gas, temperature, pressure, humidity, and flow rate. All displays and controls to be in real time and designed to permit recording of required parameters.

General assumptions for determining the quantity of ETO and N_2 gas for the terminal ETO decontamination cycle, noted in the functional design requirements were as follows:

- The shroud is assumed to be cylindrical in shape with a length of 22 feet, diameter of 260 inches (21.6 feet), cross sectional area of 370 $feet^2$ and volume of 8150 $feet^3$.
- The planetary vehicle is estimated to have a total parts volume of 40 percent of the shroud equal to 3260 cubic feet. This volume is included in an envelope approximately 20 feet long, giving an effective cross sectional area of 163 square feet.
- The effective cross sectional area of the void volume in the shroud is 207 square feet.
- The desired linear flow rate of ETO past the planetary vehicle is 1 in./min (0.0834 ft/min.)
- The ETO gas mixture will be 12 percent ethylene oxide and 88 percent Freon 12 by weight.
- The specific volume of ethylene oxide gas at 70°C, 1 atm, is 7.7 cu ft/lb
- The specific volume of Freon 12 gas at 70°C, 1 atm, is 3.13 cu. ft/lb.
- Density of ethylene oxide liquid at 68°F is 54.28 lb/ft^3.
- Density of Freon 12 liquid at 70°F is 78.3 lb/ft^3.
- Planetary vehicle soak time for decontamination unit design considerations will be a maximum of 24 hours.
- Specific heat at constant pressure (1 atm) for N_2 gas is 0.248 btu/lb°F.

- Specific weight of N_2 gas at 1 atm pressure, 70°F is 0.0795 lb/ft^3.
- Quantity of N_2 gas required to purge the shroud after decontamination if vacuum exhaust is not performed will be 10 times the effective void space in the shroud.
- The amount of heat required to raise the temperature of the planetary vehicle from 70° to 86°F is an estimated 70,000 btu (22,000-pound vehicle with a specific heat of 3 btu/lb.)

A functional design of the ETO decontamination unit was accomplished based upon the design requirements. A functional schematic of the unit is shown in Figure 9-7. It illustrates each major function of the unit and outlines positive control circuitry for maintaining the ETO gas parameters at the required values. The schematic also shows the system parameters to be monitored for each function. A description of the functional operation of the ETO decontamination unit follows.

The ETO mixture is supplied in liquid form and obtained either from an integral storage tank or from a facility ETO liquid storage tank. A nominal terminal ETO decontamination cycle requires 114 cubic feet of liquid ETO. It is proposed that small storage containers of ETO be located on the unit and a large storage tank be constructed within the facilities as shown in Figure 8-3. The small storage tank will be utilized for backup and ETO decontamination of the nitrogen cooling unit lines. A small gaseous Freon 12 storage supply is incorporated as a backup to perform a rapid dilution of concentrated ethylene oxide in the event that malfunctions occur, and the concentration of ethylene oxide within the ETO mixture increases significantly.

The ETO liquid is vaporized by expansion into a chamber and heated with electric heaters to a temperature necessary to ensure that ETO gas will enter the planetary vehicle compartment at a temperature of 86° to 95°F. The heater power is derived from an integral power supply and controlled by the temperature control logic. Water vapor is mixed with the heated ETO gas to attain the required relative humidity. It is injected into the humidification chamber through a valve operated by the humidity control logic system and mixed into the ETO gas by an agitation system. The ETO gas passes into a test plenum chamber

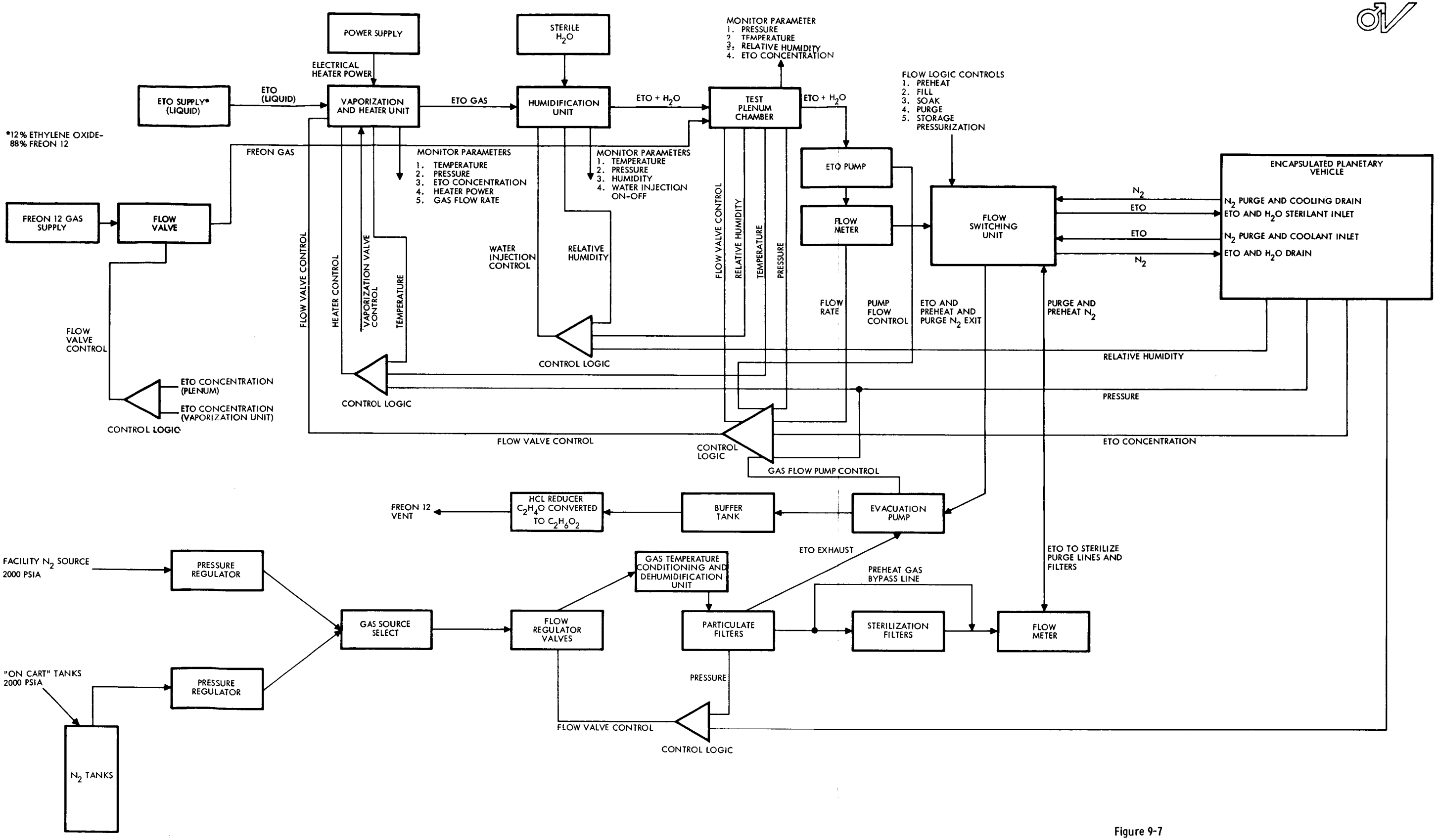


Figure 9-7
ETO DECONTAMINATION UNIT FUNCTIONAL SCHEMATIC illustrates basic operational features.

FOLDOUT FRAME

FOLDOUT FRAME

9-19A

9-19B

where a final check is made of temperature, pressure, and relative humidity prior to being injected into the planetary vehicle compartment. This chamber also serves as temporary storage for conditioned ETO gas, and will aid in smoothing out minor variations in the humidity and temperature of the gas coming from the humidification unit.

ETO temperature is sensed in the planetary vehicle compartment, test plenum chamber, vaporization and heater unit. A weighted average of these readings is derived by a summing amplifier and compared to an adjustable reference voltage representing the desired temperature. The difference in voltage is used to control the application of power to the heater units. Individual temperature readings are taken from gas samples and used to control emergency operations of the heaters. All temperature readings are displayed on the control console, and provisions are incorporated to record real-time temperature of the ETO gas during the entire decontamination cycle. The ETO temperature and concentration is measured in a similar manner as discussed in Section 9.1.1.4.

The relative humidity of the ETO gas is sensed in the planetary vehicle compartment, test plenum, and humidification unit. These readings are summed to derive a weighted average. This average is compared to an adjustable reference voltage representing the desired relative humidity in the planetary vehicle compartment. The difference in voltage is utilized to control the injection of water vapor into the humidification chamber. Since relative humidity of the gas is a function of temperature and density of water vapor in the gas, it is necessary to use the temperature values as a weighting parameter in the humidity control logic. Since the normal gas temperature range is 86° to 95°F, this weighting relationship should be sufficiently linear to mitigate the use of any nonlinear electronics in the control logic. Currently, it is expected that the humidity of the ETO will be monitored using a nondispersive infrared technique, described in Section 9.1.1.4. This technique is based on a comparison of the degree of absorption of infrared radiation by a reference gas and the test sample gas. The humidity indicator instrument output is an AC signal proportional to

the absolute humidity. The signal is converted to relative humidity in a proportional gain amplifier and recorded in real-time during decontamination operations.

Since the pressure within the planetary vehicle compartment will be limited to 0.5 psig and flow rates for ETO purge and preheated gas will vary up to 800 cu. ft/min, both an inlet pump and an evacuation pump at the planetary vehicle compartment outlet is required. Positive flow of purge and preheat nitrogen is supplied by utilizing existing storage tank pressure regulated through appropriate control valves. In addition, safety valves are utilized on the inlet side of the vaporization and heater units and test plenum chamber. Control of the pumps and valves is based upon sensing the gas pressure in the planetary vehicle compartment, test plenum chamber, particulate and biological filters, and the flow rate of ETO in and out of the planetary vehicle compartment. These signals are processed by appropriate control logic and summary amplifiers and compared to a series of reference voltages set to indicate required pressure and flow rates. Resultant differences in voltage are utilized to control system pumps, regulators, and flow control valves.

The recommended ETO disposal unit required to adequately dispose of the toxic and highly flammable ethylene oxide contains a buffer tank and ethylene oxide reduction unit. The method chosen for the ETO disposal during the preliminary design of the ETO decontamination unit is a chemical one, in which the ethylene oxide is converted to ethylene glycol and ethylene chlorohydrin by passing the ETO through a dilute aqueous solution of hydrochloric acid. The Freon 12 gas will bubble through the hydrochloric acid solution and vent safely to the atmosphere. The remaining liquid will consist of a neutral solution which may be disposed in a conventional manner, as described in Section 8.

Another possible method of ETO disposal involves the concept of catalytic burning. In this method the ETO is injected into a chamber and passed over heated coils to provide an adequate temperature rise to enable burning of the ethylene oxide (Figure 9-8). Fuel may be required as an additive to aid in combustion. Additional investigation will be necessary to prove the feasibility of this concept since elements

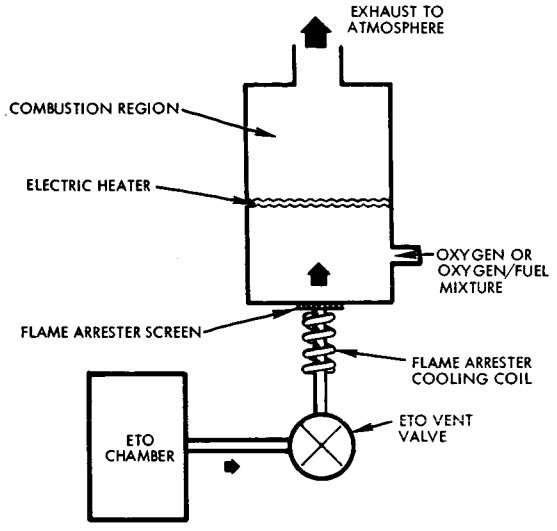


Figure 9-8
A PROPOSED METHOD FOR ETO DISPOSAL employs catalytic burning.

which are extremely corrosive will exist as a product of combustion, and control of burning rate would undoubtedly be required to preclude explosive reaction of ethylene oxide.

The purge and preheat cycle nitrogen gas supply is obtained either from storage tanks located on the unit, or from a central nitrogen storage facility. In normal operations, the facility source is utilized and the storage tanks only required for purging nitrogen cooling unit lines after cooling unit line ETO decontamination prior to use of the cooling unit. A dual set of particulate and biological sterilization filters are planned to decontaminate the nitrogen gas. The particulate filters will be of an ultra-high efficiency type to remove all foreign particles in the purge gas down to 1.0 micron. Following this, a biological filter removes biological organisms down to 0.45 micron. A filter bypass line is included which may be utilized to supply non-sterilized nitrogen gas for the preheat cycle. A temperature conditioning and dehumidification unit is required for the preheated and purge gas. This unit drys the gas to a 15 ±5 percent relative humidity, and maintains a temperature range of 90° to 95°F.

Based on the requirement for one terminal ETO decontamination cycle for each of the three flight-ready planetary vehicles, one portable ETO decontamination unit will be required at the launch site. However, one will be utilized in the manufacturing area also, and can serve as a backup unit for launch site operations. Sizing of the facility storage and the storage tanks on the unit will depend on the frequency of tank replenishment. A minimum of three complete terminal ETO decontamination cycles will be required for each Voyager mission. In the event that the biological barrier must be broken after the terminal ETO decontamination cycle, because of subsystem malfunctions or other contingencies, the terminal ETO decontamination cycle must be repeated. These requirements must be accounted for in sizing the storage tank capacity.

9.2.2 Nitrogen Cooling Unit

A nitrogen cooling unit is required for each of the flight-ready planetary vehicles. The unit must have the capability of adequately removing excess heat generated by on-board spacecraft and capsule systems during the final integrated system test after the terminal ETO decontamination cycle and during launch pad precount and final countdown operations, without recontaminating the planetary vehicle compartment interior. The cooling unit will be connected to the planetary vehicle compartment by a quick-disconnect umbilical which is released at launch vehicle liftoff. The cooling unit is required only during system test operations of the planetary vehicle and will not be connected to the planetary vehicle compartment during transportation or storage activities unless additional cooling requirements based upon radiated heating or storage heating are imposed. The functional requirements for the nitrogen cooling unit are as follows:

1) To supply sterile nitrogen gas to the planetary vehicle compartment at a temperature of 55° ±5°F, pressure of 0.5 psig, and relative humidity of 15 ±5 percent.

2) To circulate sterile nitrogen gas through the planetary vehicle compartment to maintain spacecraft ambient environment at a temperature below 95°F, and pressure and relative humidity as specified above.

The following design requirements were developed for the unit:

1) To provide pressurized nitrogen gas from unit or facility storage tanks.

2) To condition the nitrogen to 15 ±5 percent relative humidity and 55° ±5°F.

3) To decontaminate the nitrogen prior to entering the planetary vehicle compartment.

4) To circulate the conditioned nitrogen through the planetary vehicle compartment at flow rates up to 800 cu. ft/min while maintaining an internal planetary vehicle compartment pressure of 0.5 psig.

5) To provide closed-loop control of the nitrogen and planetary vehicle compartment ambient temperatures and humidity.

A preliminary functional design for the nitrogen cooling unit was generated (Figure 9-9). During planetary vehicle operations, particularly on the launch pad, it is intended that facility storage be utilized, with the storage tank on the unit employed as backup or for short emergency periods when the central facility source is disconnected. Pressure regulator and flow control valves are utilized to reduce the nitrogen storage pressure from 2000 or 3000 psia to the pressure required to control flow and permit circulation of nitrogen throughout the planetary vehicle compartment. A temperature and dehumidification unit is incorporated to adjust the nitrogen to a relative humidity of 15 ±5 percent, and to a temperature needed to control the planetary vehicle compartment ambient temperature at 70° ±10°F. Heating is accomplished through the use of electric heaters, and cooling through a closed-loop refrigerant heat exchanger.

Particulate and biological filters are utilized to decontaminate the nitrogen gas before entrance to the planetary vehicle compartment. The same filters required for the portable ETO decontamination unit will be utilized on the cooling unit; this will ease the logistics problem.

A pressure flow control logic limits the internal planetary vehicle compartment pressure to 0.5 psig during all ground cooling operations while enabling a nitrogen flow rate up to 800 cu. ft/min. The flow and

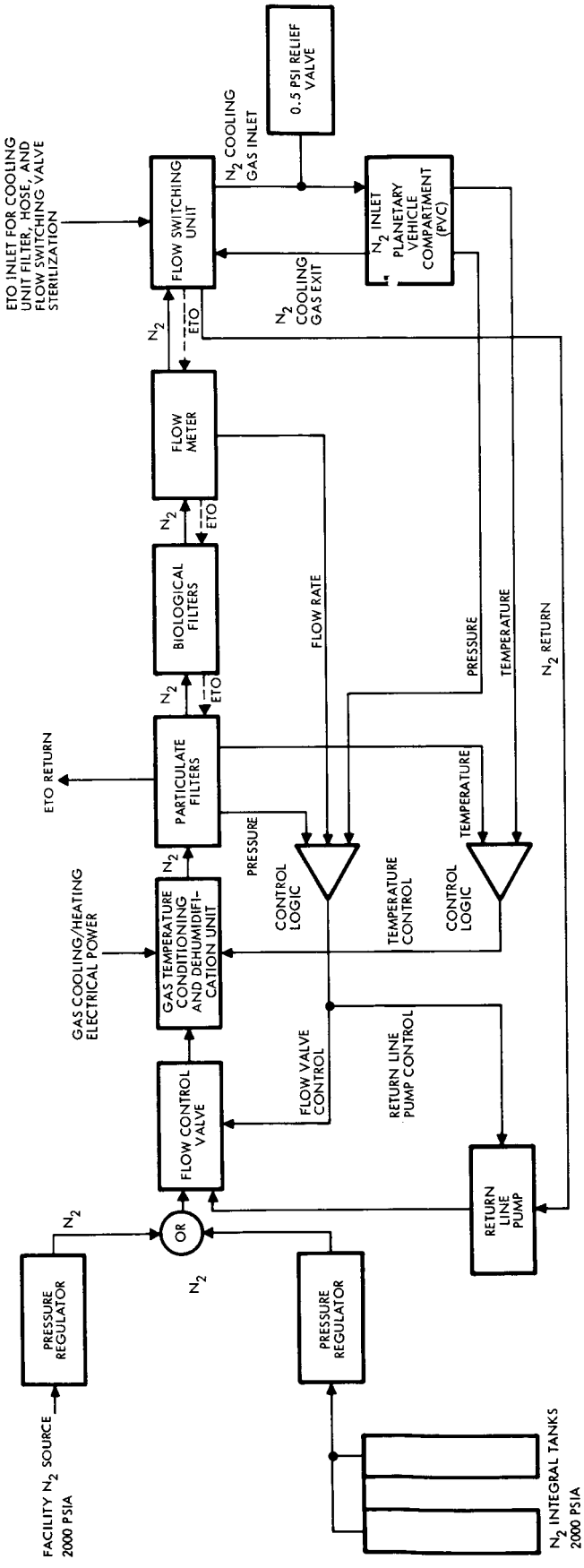


Figure 9-9
FUNCTIONAL SCHEMATIC illustrates basic operational features of sterile nitrogen cooling unit.

pressure control system is implemented by sensing the internal planetary vehicle compartment pressure and inlet flow rate. The inlet flow rate sensing is utilized to provide control inputs to the flow control valves.

A temperature control logic controls the nitrogen gas inlet temperature and flow rate, based upon inputs from the heat rejection load of the spacecraft during checkout operations. The temperature within the planetary vehicle compartment at the inlet and exit is sensed and used to provide control to the gas temperature conditioning units, flow, and dehumidification control units.

A summing amplifier is utilized to sum temperature sensor signals and provide control signals to the nitrogen heating and cooling units to maintain the planetary vehicle compartment within specification limits. The planetary vehicle compartment pressure and inlet flow rate signals also affect the flow control to guard against unsafe or overpressure flow rates demanded by the temperature control logic.

A flow switching unit is utilized to provide the capability of switching ETO gas into the nitrogen supply lines and filters, to decontaminate them prior to hookup of the cooling unit to the planetary vehicle compartment, and when biological and particulate filters are replaced.

9.2.3 Planetary Vehicle Compartment Requirements

The planetary vehicle compartment will be utilized during the terminal ETO contamination cycle to contain the ETO gas during the required soak period. The planetary vehicle is encapsulated within the planetary vehicle compartment, the compartment sealed airtight before ETO is admitted. The design of the planetary vehicle compartment must incorporate provisions to accommodate ETO inlet and outlets as well as the nitrogen preheat and purge gas, and provide special ports for biological monitoring after completion of the terminal ETO decontamination cycle. The interior of the planetary vehicle compartment must be easily cleaned of particulate matter prior to planetary vehicle encapsulation operations. The exterior of the planetary vehicle compartment should be designed to aid in cleaning prior to launch in order to limit particulate matter adhering to the exterior which may present potential contamination problems during spacecraft separation operations. Since

the planetary vehicle compartment structure limiting pressure is 5 psi, the possible mode of pulling a vacuum within the planetary vehicle compartment as part of the decontamination procedure would require utilization of a special ETO chamber in which a vacuum is pulled on the exterior and interior of the planetary vehicle compartment to equalize the pressure on the structure. Additional investigation is required to determine if other factors, such as structural limitations on the capsule, would preclude vacuum operations.

Based upon the preliminary design of the ETO decontamination unit, it is recommended that several 6-inch diameter ports for the gas inlet be mounted on the upper dome of the planetary vehicle compartment, and several 6-inch diameter outlet ports be located on the lower dome. In addition, 3-inch diameter ETO inlets should be located 90 degrees apart on the cylindrical section side structure to enable injection of the gas into the sides of the spacecraft to provide assurance that adequate ETO is circulated throughout the spacecraft interior. Circulation of the ETO during the soak period utilizing the annular planetary vehicle mounting ring may provide this capability if it is designed as a perforated tubular section and the ETO is injected into the ring. All inlet and outlet port valves must be of the quick disconnect type and be able to be sealed adequately to prevent ETO leakage, as well as to maintain a 0.5 psig positive dry nitrogen pressure within the compartment after the terminal ETO operations have been completed to preclude recontamination of the planetary vehicle compartment.

9.2.4 Transportation and Handling

Transportation, handling and storage of the spacecraft and planetary vehicle assembly between operational areas will be accomplished utilizing existing spacecraft and/or planetary vehicle protective coverings. All handling equipment such as hoist beams, etc., will be designed so that they can easily be cleaned, and heavy particulate matter removed prior to any major handling operation for the spacecraft. All work stands and supporting structures will be designed under the ground rules that easy access will be provided for cleaning operations on the spacecraft and workstand areas.

9.2.5 Checkout Equipment

All checkout equipment for the spacecraft and planetary vehicle will be located in an adjoining room outside of the clean rooms, insofar as possible. Where it is mandatory that the checkout and other associated equipment be located adjacent to the spacecraft and/or planetary vehicle, equipment must be designed to lend itself to easy cleaning to reduce particulate contamination and the possibility that the checkout equipment may contaminate the spacecraft. Design considerations are to provide 1) minimum inside corners, return edges, etc., in which particles may lodge and be retained; 2) filters on cooling blowers on each item of equipment for both the intake and exhaust when the blowers must exhaust directly into the working area; and 3) equipment that can be easily vacuum cleaned prior to usage. The requirement for clean room operations will apply only to particulate control, and no special additional design features to prevent biological contamination are necessary.

9.2.6 Contamination Control Monitoring and Cleaning Equipment

Equipment to aid in monitoring particulate and biological contamination of the spacecraft and the clean room facilities will be required. The equipment consists of microscopes, infrared sensing equipment, and other associated monitoring and control equipment as described in Section 9.1.

The same types of cleaning equipment as utilized in the manufacturing area will be required at the launch site, such as vacuum cleaners, ultrasonic scrubbers, etc., (Section 9.1.4).

9.3 SAFETY

There are no special safety requirements imposed upon the equipment by contamination control except those imposed by ETO operations. These are discussed in Sections 8.3 and 9.2 of this volume.

10. IMPACT OF DECONTAMINATION ON PROGRAM SCHEDULES

10.1 CONCLUSIONS

The impact on the spacecraft schedule imposed by contamination control and ETO decontamination requirements is illustrated in Figure 10-1 showing the major contamination control tasks. The duration of each task is indicated by calendar year. The schedule indicates that contamination control and ETO decontamination impose additional manpower requirements on the program for the design, construction, and testing of specialized facilities and equipment required to accomplish contamination control operations.

These tasks require manpower allocations for coordination and program control throughout the entire spacecraft program to achieve adequate integration with other program requirements. The affect of the contamination control and ETO decontamination requirements on each major segment of the spacecraft operations from engineering design through launch are described below.

10.2 SPACECRAFT DESIGN FOR DECONTAMINATION REQUIREMENTS

Rigid contamination control, both particulate and biological, (see Section 6) imposes specific design requirements on the spacecraft system, subsystem, unit, and piece part level in order that compatibility with particulate control and ETO decontamination cycles is assured, and the mission is not degraded due to contamination control requirements.

Surveys are and will continue to be conducted to isolate materials and components which may not be compatible with ETO decontamination cycles. When ETO incompatible items are found to be required by a specific design and no substitute is available, it becomes necessary to encapsulate the material or component in a hermetically-sealed container to prevent the ETO from coming in contact with the surface.

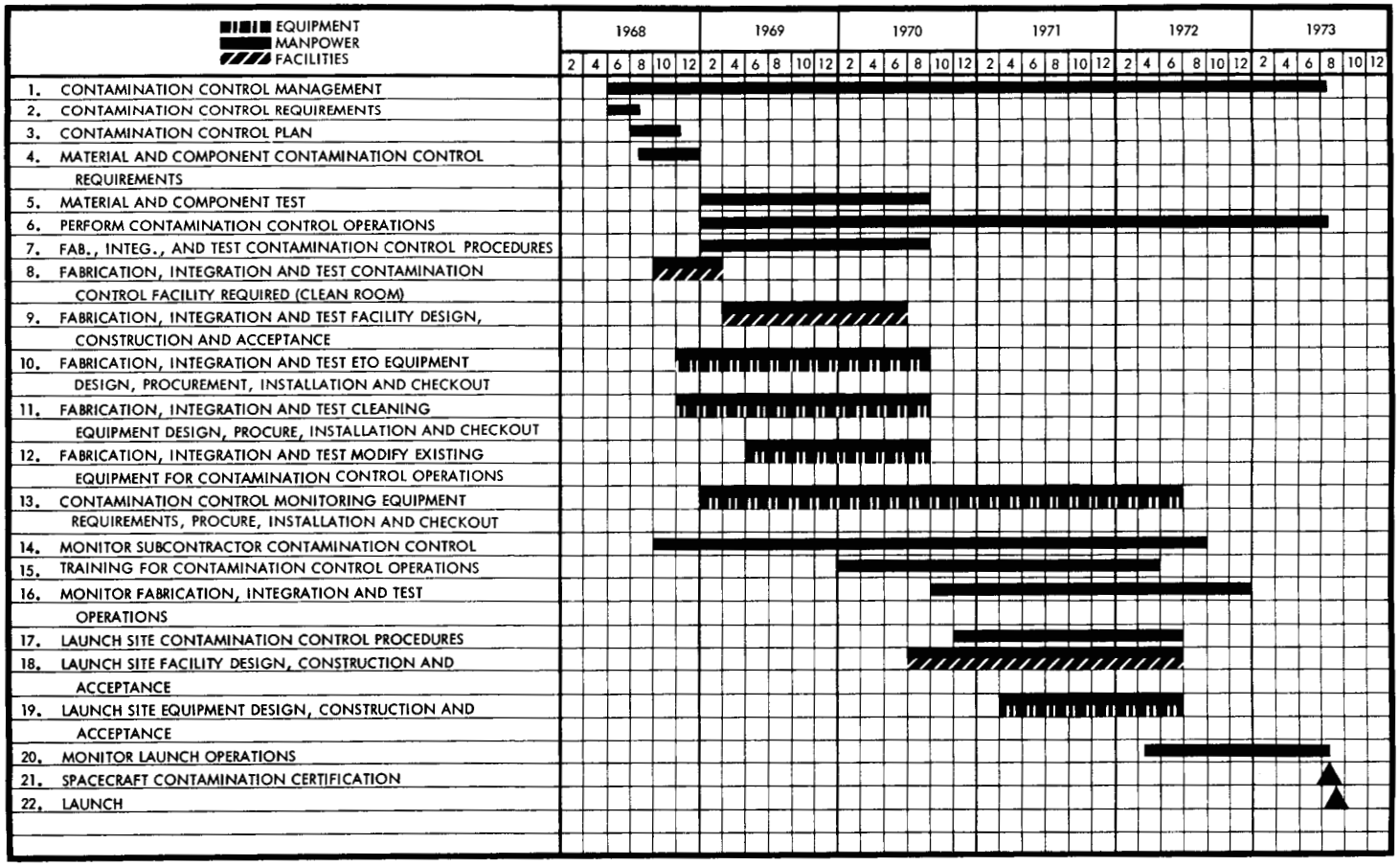


Figure 10-1

THE CONTAMINATION CONTROL SCHEDULE illustrates the sequence of task performance of major contamination control implementation tasks.

Figure 10-2 illustrates the impact upon the spacecraft subsystem design of ETO compatibility and the necessary design and test tasks imposed. Additional man-hour allocations are required for design and test coordination, and selection of proper materials and components for ETO compatibility. In addition, man-hours are required to conduct an extensive material and component compatibility testing program to cover adequately the broad range of materials and components required by all spacecraft subsystems.

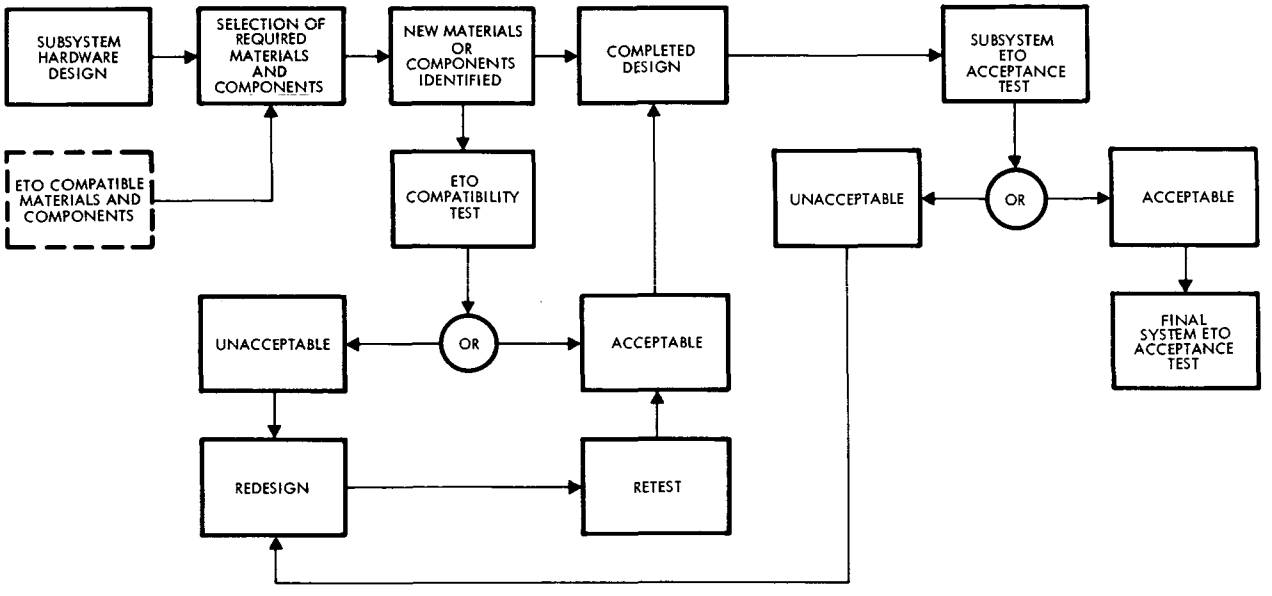


Figure 10-2
ASSURANCE OF SPACECRAFT COMPATIBILITY with ETO requires testing at the levels shown.

The test program involves the search and selection of required materials and components, procurement of adequate test samples, preparation of a test program, testing and summarizing results. In addition, close liaison with all design groups is mandatory in order to maintain an up-to-date list of required as well as tested and acceptable materials and components. The test program also requires the utilization of special facilities and equipment.

After the final unit design has been completed, a unit qualification test is required. The unit is checked out and tested for functional performance, and an ETO decontamination cycle is performed utilizing ETO qualification test procedures as outlined in Appendix B. A final unit func-

tional test is performed after the ETO exposure to verify system performance. If the unit has been degraded after the ETO cycle, redesign may be required. This process is accomplished for each spacecraft unit. A final proof of ETO compatibility of the complete spacecraft design is provided during the system level ETO decontamination proof test conducted on the spacecraft proof test model. After successful completion of the proof test model ETO decontamination cycle, and adequate system functional performance checkout is completed, to clearly demonstrate that ETO decontamination has not affected spacecraft performance, the design phase of the spacecraft which considers ETO decontamination requirements has been completed.

The impact on the spacecraft design schedule of the ETO decontamination requirement will not affect major milestones, if the assumption is made that redesign is limited to minor changes. However, if major design problems arise during subsystem or system qualification ETO testing, necessitating major redesign and retesting, additional manpower is required and major milestone may require readjustment. To avoid this contingency, major testing of a majority of materials and components should be accomplished prior to the final subsystem and system design reviews.

10.3 FACILITY DESIGN FOR CONTAMINATION CONTROL

Specialized facilities must be designed and constructed, or facilities utilized for existing spacecraft operations must be modified in order to accommodate spacecraft ETO decontamination requirements and particulate contamination control (Section 8). Each area must be designed or redesigned to incorporate FED-STD-209, class 10,000 clean room requirements. These facilities include the spacecraft assembly area, selected areas for unit assembly and test, and spacecraft test areas, such as the thermal vacuum chamber, anechoic chamber, and shock and vibration facilities. Launch site facilities include areas for spacecraft and planetary vehicle operations.

Clean room requirements impose additional man-hours for the detail design of required operational areas. Approximately 20 percent increase in total design manpower is required to accomplish these tasks. In addition, clean room facility construction time and cost is increased by

approximately the same percentage over that of a standard spacecraft assembly facility. It has been estimated that approximately 1 year is required to construct a new spacecraft assembly facility incorporating class 10,000 clean room requirements. This estimate compares with approximately a 9.5- to 10-month estimated time for construction of a standard spacecraft assembly facility without clean rooms. The effect on the program schedule of the additional design and construction time is that initiation of facility design and construction must be accomplished several months earlier than normally planned in a standard spacecraft program. The Voyager facilities must be initiated at contract go-ahead. An alternate to an early start on facility design and construction is the initiation of multiple shift operations, which increases program cost.

Included in the manufacturing and launch site facility design is the requirement to incorporate ETO test and storage facilities. Several areas for ETO storage will be required in the manufacturing area and one is required at the launch site. The storage facilities include a storage tank and plumbing necessary to route the ETO to the various locations in which ETO chambers are to be operated. Additional tradeoff studies will be necessary to establish whether one centralized ETO storage facility at the manufacturing area, to service a number of scattered test chambers, or several smaller storage facilities selectively located, will be optimum in terms of cost and construction schedule. Design and construction time must be allocated to this task.

Routine maintenance of manufacturing area and launch site clean room facilities and ETO decontamination facilities will require an increase in maintenance personnel due to the additional tasks necessary in changing filters, periodic checking of ETO plumbing for leaks, etc., on a regularly scheduled basis.

Additional design and construction time will be required for modifications to the launch pad area at Kennedy Space Center launch complex 39 to accommodate the two nitrogen cooling units necessary to provide sterilized dry nitrogen cooling gas to each planetary vehicle during prelaunch checkout and terminal countdown. These modifications include provisions for mounting the cooling units within the umbilical tower and adding the required cooling umbilical lines, necessary structural support, and ejec-

tion mechanism. In the case of launch complex 39 pad modifications, all construction modifications must be scheduled within the existing launch schedules of other Saturn V launch vehicles on a noninterference basis.

In summary, facilities needed to incorporate requirements for ETO decontamination will require additional manpower for the increased design tasks, construction time, and facility maintenance time. Use of multiple shift operations for both design and construction may be required to meet program dates.

10.4 EQUIPMENT DESIGN

Items of specialized equipment required for ETO decontamination and contamination control are identified and discussed in Section 9. Among these items are the ETO decontamination unit and the nitrogen cooling units required at the launch site. Other items of equipment are required to maintain contamination control, such as cleaning equipment, biological monitoring equipment, particulate contamination monitoring equipment, and equipment required to maintain class 10,000 clean room environments. In addition, ETO chambers for piece part and component evaluation and testing will be required during the initial design and qualification phase of the program.

In this study, it has been assumed that equipment required for biological and particulate monitoring, and of clean room operations (including the piece-part, unit, and system cleaning equipment such as vapor degreasers, vacuum cleaning equipment, etc.), will be existing designs or off-the-shelf procurement items; therefore, no additional design, fabrication, or test time for either the prime contractor or other contractors is assumed. The only requirement for obtaining this equipment is the establishment of procurement procedures, selection of required items of off-the-shelf equipment to satisfy all spacecraft program requirements, and installation in the contractor's facility.

The ETO decontamination unit and the nitrogen cooling unit will be designed to meet specific program requirements. After the detail design has been completed, fabrication and component procurement will be accomplished and the units assembled. Initial testing will be performed to assure that the equipment meets its performance design requirements.

The tests will include functional performance as well as checkout of the instrumentation and control circuitry of each design. Each item of equipment will be acceptance tested utilizing the spacecraft proof test model test program as the final acceptance test sequence. The requirement for this specialized equipment adds man-hours for design, fabrication, component procurement, installation, checkout, and acceptance testing (Figure 10-3).

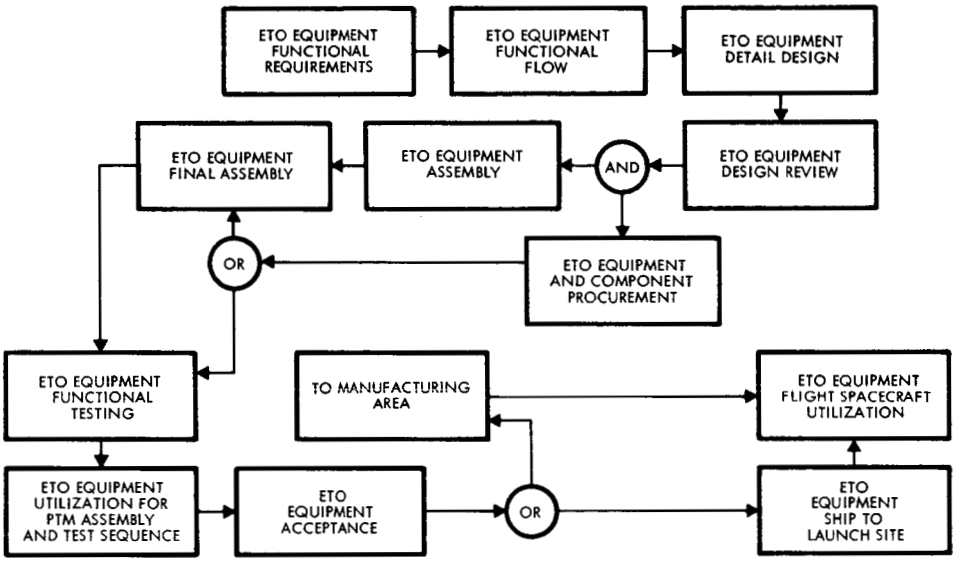


Figure 10-3
ACQUISITION AND UTILIZATION FUNCTIONAL FLOW is shown for ETO equipment.

10.5 INTEGRATION AND TEST

During spacecraft assembly, integration, and test, the requirement for ETO decontamination and particulate contamination control will impose additional manpower and operational constraints on the spacecraft program schedule. Contamination control requirements are imposed on the methods of spacecraft operations; therefore contamination control operational procedures must be generated for each segment of the assembly, integration, and test operations, from piece part fabrication through final acceptance test and preparation of the spacecraft for shipment to the launch site. Each step of the spacecraft fabrication, assembly, and test operations must be thoroughly analyzed and contamination control procedures written into each operation. This procedure preparation will require considerable manpower allocations. Contamination control procedures will be generated

as spacecraft detail design progresses, and interfaces between design and manufacturing planning operations considered.

Preparation of the contamination control procedures will be based upon the flow chart sequence shown in Figure 10-4. In preparation of the procedures, the end date for the first procedural drafts will coincide with the initiation of the engineering model spacecraft operations. The procedures will be instituted during the EM fabrication and assembly. Modifications and alterations to the procedures, based upon inputs obtained during EM operations, will be incorporated and final validation of the procedures completed during the fabrication, integration, and test of the proof test model spacecraft. Final procedural changes will be instituted based upon the results of the PTM operations, and incorporated prior to initiation of the first flight model spacecraft operations. Coordination between engineering design, integration, and test planning will be continued to maintain the procedures in a current status at all times, and to correct deficiencies or delete procedures where it is determined that they are no longer required to maintain the spacecraft in the required decontaminated condition.

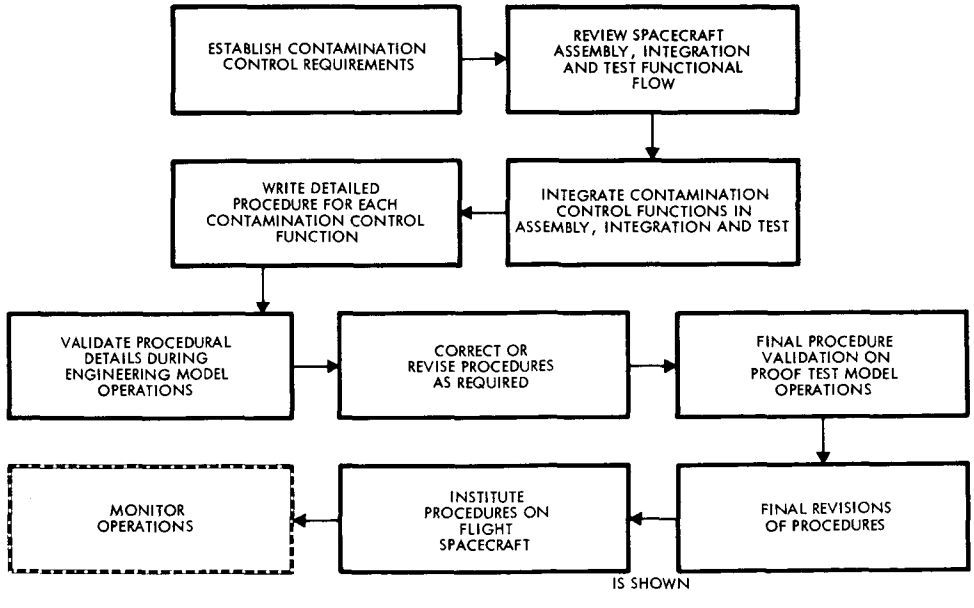


Figure 10-4
FUNCTIONAL FLOW is shown for generation of required contamination control procedures for spacecraft assembly, integration and test operations.

Each contamination control procedure which interfaces with material and component fabrication, qualification, and spacecraft assembly, integration, and test operations must be completed and verified in the proper sequence to be compatible with the manufacturing schedule. Adequate manpower must be allocated to coordinate, prepare, and verify the procedures to meet critical due dates.

Contamination control procedures will require allocation of additional man-hours for personnel preparation prior to entering clean rooms, daily vacuum cleaning requirements, etc. The working day in terms of productive labor achieved by each personnel will be reduced by the additional contamination control procedures required. Therefore, in order to meet the spacecraft operation and test schedule, it may be mandatory to schedule multiple shift operations to make up for the additional man-hour loss due to the requirements for contamination control.

The requirement for an ETO decontamination acceptance test of the spacecraft prior to shipment to the launch site must be incorporated into the schedule. This ETO acceptance test will require an additional two weeks of test time which would not be needed if the ETO decontamination requirements were not included in the overall program. The 2-week schedule for the spacecraft decontamination is a minimum requirement. If extensive rework due to a system malfunction occurs after the ETO cycle, an additional ETO decontamination cycle may be required. This sequence of events does not appear in the normal spacecraft integration and test schedule; if required, a significant schedule impact may occur.

In summary, during spacecraft assembly, integration, and test operations, schedule impacts are noted due to requirements for contamination control and ETO decontamination of units and the spacecraft system. Reduced effective man-hours per working day because of the preparation of personnel for clean room operations, as well as additional cleaning requirements imposed during all phases of operations also affect the overall schedule and manpower loading. These requirements have the effect of either stretching out the total spacecraft integration and test

schedule, or imposing the requirement that multiple shift operations be scheduled to maintain a shorter calendar time for the sequence of events.

10.6 LAUNCH OPERATIONS

The requirements for contamination control and a terminal ETO decontamination cycle, accomplished on the planetary vehicle after encapsulation within the planetary vehicle compartment, impose constraints on prelaunch and terminal countdown schedules. The schedule impact of launch site contamination control and ETO decontamination are similar to those discussed in the integration and test activities. Preparation and validation of procedures for contamination control through prelaunch operations will be required and accomplished in the same manner, (Figure 10-4) and will include cycling of the proof test model through the complete launch site operations.

The requirement to maintain the encapsulated planetary vehicle in a decontaminated condition after the terminal ETO decontamination cycle precludes additional work being performed on the spacecraft subsystems. Therefore, if subsystems performance does not meet specification requirements during the final integrated system test, it will be necessary to repair or adjust the faulty system and perform the ETO decontamination cycle again. The normal schedule allows a 2-week period for the ETO decontamination cycle, including installation of the planetary vehicle compartment in the decontamination chamber; connection of the proper ETO lines; supply preheating of the planetary vehicle; ETO soak for 11 to 18 hours; performance of a final biological monitoring survey for verification of an acceptable biological count, purging of the system with dry sterile nitrogen; and final integrated system test. Since three planetary vehicles must be so treated, scheduling of this operation is critical to the overall prelaunch schedule for each mission. If contingencies arise, the normal schedule provides a backup planetary vehicle and no additional time is allowed for a recycle of the ETO decontamination operation. If critical problems arise in any two planetary vehicles, serious scheduling

implications due to the replacement or repair of faulty components, re-encapsulation operations, and terminal ETO decontamination could provide a significant schedule impact. Built-in holds should be incorporated into the prelaunch schedule to provide for these contingencies.

In summary, during spacecraft prelaunch operations at the launch site, contamination control and the terminal ETO decontamination cycle will impose scheduling constraints in terms of additional manpower required to accomplish these tasks, and the reduced effective man-hours per day due to stringent contamination control requirements. The effect of this implication is to make mandatory a multiple shift schedule for many launch site operations, and the incorporation of built-in holds in the prelaunch operations schedule.

10.7 PROGRAM MANAGEMENT

ETO decontamination and contamination control imposes additional manpower requirements for program management to assure that requirements based upon the contamination control plan are satisfied. This effort includes determining contamination control requirements; preparing the contamination control plan; generating instructions to functional activities on implementing the contamination control plan; determining and monitoring the budget; maintaining customer interface; certifying to spacecraft decontamination standards; monitoring contamination control; and conducting a training program.

The effect on the spacecraft schedule of additional manpower required for contamination control monitoring does not appear significant, since it is anticipated that few additional personnel will be necessary. Due to the anticipated multiple shift operations during the integration through launch cycle, program management personnel will be assigned to cover all phases of these operations. The total impact upon the schedule is additional man-hours or manpower expenditures for the total duration of the Voyager program.

An adequate personnel training program must be established to prepare spacecraft operations personnel for the contamination control procedures required during all phases of spacecraft operations. This

training program will be prepared in conjunction with the contamination control procedures, and each group of operations personnel will be given a training indoctrination program to review contamination control techniques and to impress upon each individual the requirement for maintaining the spacecraft in a clean condition throughout all operations. The training program will include demonstration of cleaning procedures, biological monitoring procedures, and clean room operations. Special training classes will be given to those personnel involved directly in the ETO decontamination operations from the component and material test phase through the spacecraft system level, to provide instruction in the operation of the ETO equipment and of the safety precautions and procedures necessary during the use of this equipment.

To be included in the ETO training is a complete coverage of the characteristics of the ETO gas mixture. This is a natural prerequisite to the operational training, in which the biological and flammability hazards can be more fully explored. Printed reference materials and operational procedures will be provided to all persons engaged in ETO activities in order to enhance and maintain a high level of operator competence.

The end results of the contamination control training program will be the utilization of the contamination control and equipment facilities with a maximum of efficiency, effectiveness, and safety. It is recognized that operator capability is a major contributing factor toward the accuracy and reproducibility of exposures. The potential safety hazards, both for personnel and for equipment, which are implied by the use of a biocidal and possibly flammable agent, make it especially important to assure that all operators are adequately qualified.

The training program will require manpower allotments to prepare and conduct the training program, and utilization of personnel time to attend these classes. These training programs must be scheduled prior to the institution of the contamination control procedures which will

initially commence with fabrication of the spacecraft engineering model and which will be in full operation during the spacecraft proof test model fabrication, assembly, integration, and test operations. The adequacy of the training program will also provide an impact on the schedule, since inadequately trained personnel can add to the contamination of the spacecraft and necessitate additional cleaning operations during assembly, integration, and test operations.

A training program will also be accomplished for launch site personnel. Since the majority of the personnel involved in the manufacturing area integration and test activities will be transferred to the launch site, the necessity for duplicate training programs during launch preparation will be eliminated and only those activities connected with the terminal ETO decontamination cycle will require an additional training program. Launch site contamination control training will include the operation of the ETO decontamination unit and nitrogen cooling unit, including routine maintenance.

The schedule considerations of personnel time involved and preparation for clean room operations, etc., will apply to launch site operations in a similar manner indicated in the assembly, integration, and test operations in the manufacturing area.

APPENDIX A

REFERENCES

This section lists references cited in Sections 7 through 10 of this volume.

1. Schwartz, Oscar A., "Effect of Gas Sterilization (Ethylene Oxide) on Various Electronic Components," Report No. 7-0077, JPL Task 54, Librascope, May 5, 1964.

2. Willard, Myra, "Surveyor Sterilization Part III: Further Compatibility Studies of Materials and Components with Ethylene Oxide-Freon 12 and Heat," Hughes Aircraft RS-292, July 1962.

3. Willard, Myra and V. K. Entrekin, "Surveyor Sterilization Part II: A Literature Review of the Physical, Chemical, and Biological Properties of Ethylene Oxide-Freon 12 and 15s Compatibility and Materials and Components," Hughes Aircraft RS-283, March 1962.

4. Willard, Myra, "Surveyor Sterilization Part I: Compatability of Materials and Components with Heat and Ethylene Oxide Freon 12," Hughes Aircraft RS-277, January 1962.

5. Rydelek, R., "Study of the Effects of Ethylene Oxide-Freon 12 Upon Properties of Polymers and Metallic Surface," Hughes Aircraft P-65-57, JPL Contract 951003, Interim Status Report, October 1, 1964 through April 30, 1965.

6. Willard, M., "Report of NASA National Conference on Spacecraft Sterilization," TRW Systems Interoffice Correspondence 9371.2-1698, December 1, 1965.

7. Dick, Marshall and Charles E. Feazel, "Resistance of Plastics to Ethylene Oxide," Modern Plastics, Vol. 38, Sec. 1, (November 1960), p. 148.

8. Motorola Test Memo. 611, "Qualification Test of Thirty Hughes Type HC-7051 Silicon Voltage-Variable Capacitor Diodes," July 12, 1961.

9. Dalton, R.P., "Report on Qualification Test on Power Rectifiers HF5D from Gemini Reliability," Associated Testing Labs., Inc., Test Report No. H 191-3764 (9762), July 14, 1963.

10. Hanks, C. L. et al., "Qualification of Capacitors for Jet Propulsion Laboratory Preferred Parts List," 152.00-01, Battelle Memorial Institute, October 30, 1964.

11. Pedulla, J. V., "Report of Qualification Test on Diode HF2C from Gemini Reliability," Associated Testing Labs, Inc., Test Report 9763, October 11, 1963.

12. Wood, Wm. P., "Qualification Test Report, Capacitors, Metallized Mylar, Cornell-Dubilier Electric Corp., Type TWMM, OR 5791," Bendix Corp., June 1962.

13. Guthery, G. H., "Environmental Test Report for Formica Type FF91 and EXP 783 Printed Circuit Board Material," Brown Engineering Co., Inc., May 19, 1964.

14. Varga, R. J., "Final Sterilization Report," Vol 1, SSD3372R, Hughes Aircraft, June 1963.

15. Vaccaro, J. and N. C. Gorton, "RADC Reliability Physics Notebook," RADC-TR-65-330, Battelle Memorial Institute, October 1965.

16. Opfell, John B. et al., "Sterilization Handbook," SN-37 Final Report, NASA Contract NASW-777, Dynamic Science Corp., August 26, 1964.

17. Tarpley, John L., "Adverse Effects of Cry-oxide Sterilizing Agent on Sprague Type 109D Capacitors," IDEP Report, No. 347.15.000.00-H6-01; FAR 1520--3, June 1966.

18. Calof, R., A. Dembolt, J. Hamer, D. Kessler, T. Thompson, and G. Winterton, "A Study of Critical Sterilization Problems on a Mars Atmospheric Entry Probe," Northrop Corp, Vol II, June 1966

19. Rydelek, R. F. and A. L. Landis, "Study of the Effects of Ethylene Oxide-Freon 12 upon Properties of Polymers and Metallic Surfaces," Final Report, Aerospace Group, Hughes Aircraft Company, P66-96, June 1966.

20. Willard, M. T. and E. R. Zobel, "Study of Ethylene Oxide Effects on Components," TRW Systems, 5538-6002-R0000, June 1966.

21. "Comparative Studies of Conceptual Design and Qualification Procedures for a Mars Probe/Lander," Volume IV, Sterilization, Avco Corp., Report No. AVSSD-0006-66-RR, May 1966.

22. Muraca, R. F., N. Fishman, A. A. Kock, and J. S. Whittick, "Polymers for Spacecraft & Hardware," SRI, Report No. ASD 5046 #28 (66-621), October 1966.

23. Colvit, C. N., "Marking and Identification" TRW Systems, TR5522-6002-R0000, May 1966.

24. Babjik, S. J., etc., "Planetary Vehicle Thermal Insulation Systems," G.E., March 1967.

25. Okumura, J., "TRW Materials Compatibility Study With Ethylene Oxide Freon 12 Decontamination Processes," TRW Systems 09133-6003-R000, September 1967.

26. Charles, F., M. Neudorffer, "The Effect of Relative Humidity on Aluminized Mylar Films," TRW Systems, 7421.1-388, VVV-569, August 1967.

27. Wolf, H. W. et al, "Sampling Microbiological Aerosols," Public Health Monograph No. 60, Public Health Service Publication No. 686, August 1965.

28. Puleo, J. R., M. S. Favero, and G. J. Tritz, "Feasibility of Using Ultrasonics for Removing Viable Microorganisms from Surfaces," Contamination Control, VI, No. 4, April 1967.

29. McDade, J. J., "Techniques for the Limitation of Biological Loading of Spacecraft Before Sterilization," COSPAR Symposium on Sterilization Techniques for Instruments and Materials as Applied to Space Research, London, Eng., 1967.

30. Dugan, V. L., "A New Approach to the Microbiological Sampling of Surfaces; The Vacuum Probe Sampler," SC-RR-67-114, Sandia Laboratory Report, March 1967.

APPENDIX B

SAMPLE ETO QUALIFICATION AND ACCEPTANCE TEST SPECIFICATION

This specification is a revision of JPL Specification VOL-50503-ETS. The basis for the revision was to reflect requirements for spacecraft ETO exposure, simplify operation sequences, and minimize deleterious ETO effects on materials. Significant specification changes were to reduce exposure duration and cycles; optimize ETO concentration, relative humidity, chamber temperature, and pressure to ensure adequate gas formation.

1. SCOPE

This specification defines the environmental test requirements and procedures for spacecraft qualification and flight acceptance testing to show compatibility with ETO decontamination environments for spacecraft system elements. The specification covers unit level and system level tests, and defines the minimum test limits for components and materials intended for flight. By specifying test procedures, uniform laboratory tests are established which provide confidence in the capability of the units to perform satisfactorily in the expected environments.

2. APPLICABLE DOCUMENTS

The following documents of the issue shown form a part of this specification to the extent specified herein.

SPECIFICATION

TRW Systems

	Ethylene Oxide-Freon 12 Decontaminating Agent, Material Specification (to be prepared)

STANDARD

Federal

FED-STD-209	Federal Standard Clean Room and Work Stations Requirements, Controlled Environment

3. REQUIREMENTS

3.1 Precedance of Specifications

This specification, concerned with environmental test requirements to show compatibility with ethylene oxide-Freon 12 (ETO) decontamination environments, will be considered an applicable document to the environmental qualification and flight acceptance test specifications for spacecraft systems, units, materials and components.

Special consideration for individual units, parts, and materials, may require modification of the test procedures stated herein. Considerations, additions, or deviations from this specification, incorporated in the unit test specification, will be permitted upon approval by the spacecraft system manager. Test specifications which contain approved deviations and special tests will take precedence over this specification.

3.2 Configuration

In all instances, except when evaluating materials, the configuration under test will be a flight configuration; and the configuration of the test unit will be stated in the appropriate test specification. In all tests, cables, plugs and other fittings normally associated with the assembly or system will be used and considered part of the assembly or system.

It is assumed that this level of equipment represents the configuration which would be stocked as spares. Environmental qualification and flight acceptance test specifications would be written for each equipment grouping. Such groupings of hardware are defined as "provisioned" spares.

3.3 Preparation of Environmental Test Specifications

Environmental qualification and flight acceptance test specifications for component and material qualification will be prepared for each equipment grouping. Spacecraft design organizations governed according to the requirements of this specification are expected to prepare environmental test specifications and perform testing in a manner consistent with the intent of this and other general environmental specifications appropriate to each test item. As a minimum requirement, the tests specifications will include the following:

a) Identification of equipment configuration subjected to tests

b) Environmental qualification and flight acceptance tests consistent with this specification

c) Performance criteria, by which the acceptance or rejection of the assembly is determined

d) Pre- and post-environmental test performance checks where applicable

e) Description of required test support equipment

Bench performance testing may be included. Each environmental test specification will be subject to review and approval of the spacecraft environmental requirement engineer as a portion of the unit level design review in advance of commencement of qualification and flight acceptance environmental tests.

3.4 Preparation of Detailed Operational Procedures

Detailed operational procedures for the performance of these tests will be prepared. These procedures will be subject to approval of the spacecraft environmental requirements engineer. The procedures will present the detailed method of test and test control, instrumentation system, calibrations, checkout, and data verification.

3.5 Acceptable Operation

Acceptable operation will be defined in the appropriate equipment test specification. A visual inspection for physical damage will be performed at the conclusion of a test series. Equipment under test is not required to operate, but only to survive the imposed environment. The equipment must function in accordance with its appropriate specification after completion of testing. Inability to comply with this requirement will be defined as a failure. Any failure that occurs during a test cycle will be cause for the discontinuance of testing. Any unit repaired after a failure or malfunction is considered an untested unit and will be retested subject to Section 3.1.

3.6 Qualification Testing for ETO Compatibility

Qualification tests will be performed on equipment in a flight configuration and any subsequent design change or flight acceptance configuration change will, in general, invalidate the ETO qualification tests. Units subjected to qualification tests are disqualified for flight. To successfully pass ETO qualification tests, equipment will function in accord with its detail specification.

3.6.1 Materials

Each polymeric material used on the spacecraft will be qualified for compatibility with ETO by subjecting it to six ETO exposure cycles. Each polymeric material will be evaluated separately and apart from its adjacent component. Physical and mechanical properties of the material will be measured before and after decontamination. The properties measured will depend on anticipated use of the material. Standardized test methods (ASTM) will be used for testing and evaluating materials where feasible.

3.6.2 Components

All components used on the spacecraft will be qualified for ETO compatibility by subjecting them to six ETO exposure cycles. Performance tests and other evaluation criteria for determining the effects of ETO on components will be accomplished before and after ETO exposure.

3.6.3 Units

All units used on the spacecraft will be qualified for ETO compatibility by subjecting them to six ETO exposure cycles. Performance tests and other evaluation criteria for determining effects of ETO on the units will be accomplished before and after the ETO exposure.

3.6.4 Proof Test Model

The spacecraft proof test model will be qualified for ETO compatibility by subjecting it to six ETO exposure cycles. Performance tests and other evaluation criteria on the proof test model will be accomplished prior to and after each ETO exposure cycle to determine the effects of ETO. Contact of the ETO atmosphere on all primary surfaces of the spacecraft system is required.

3.7 Flight Acceptance Test

Each flight unit and flight spacecraft will be subjected to one ETO exposure cycle. Performance tests and other evaluation criteria for determining the effects of ETO will be accomplished before and after the test.

3.8 ETO Decontamination Test Requirements

Spacecraft elements undergoing ETO qualification or flight acceptance testing will be subjected to ETO in an enclosed test chamber capable of producing a controlled environment of time, temperature, relative humidity, pressure, and specified ETO concentration defined for the appropriate test:

- ETO Decontamination Agent: The decontaminating agent will contain 12 percent ethylene oxide and 88 percent dichloro-difluoromethane (Freon 12)
- Atmospheric Concentration: The concentration of ethylene oxide within the test chamber will be within 500±50 milligrams of ETO per liter of gaseous atmosphere.
- Method of Introducing ETO: ETO will be introduced into the test chamber in a timed-programmed sequence.
- Temperature: The method of heating, cooling, and temperature control will be one that employs a heat exchanger and will provide an even distribution of heat throughout the chamber. Even distribution of temperatures will be as specified in Section 4.1.
- Qualification test temperature shall be 104±5°F. Acceptance test temperature shall be 86±5°F.
- Relative Humidity: The method of achieving and controlling relative humidity within the chamber will be one that assures an even distribution of water vapor and an accurate humidity control. The method used will guarantee the required RH within the specified tolerance and will be compatible with other requirements and devices for controlling temperature and ETO concentration. Relative humidity for qualification testing shall be 45±5 per cent. 40±5 per R.H. shall be utilized for acceptance testing.
- Time: Units to be decontaminated will be subjected to the stated environment for 24 hours per cycle.

3.9 Test Sequence

As a general rule, there will be a preferred sequence of testing for the various levels of equipment. As a minimum requirement, the sequences for the various levels will be as delineated below:

1) Components and materials compatibility tests

   a) Other environmental tests
   b) ETO decontamination test (six cycles).

2) Units qualification testing

   a) Select ETO qualified parts
   b) Assembly and checkout of units
   c) Other qualification environmental tests of unit
   d) ETO qualification of unit (six cycles).

3) Systems level qualification testing

   a) Assembly and checkout proof test model
   b) Other proof test model qualification and environmental tests
   c) ETO qualification of proof test model (six cycles).

4) Units flight acceptance testing (flight hardware)

   a) Select ETO qualified parts
   b) Assembly and checkout of units
   c) Other acceptance environmental tests of unit
   d) ETO flight acceptance of unit (one cycle).

5) Systems level flight acceptance

   a) Select ETO qualified parts
   b) Assembly and checkout of units
   c) ETO flight acceptance of spacecraft (one cycle).

4. QUALITY ASSURANCE PROVISIONS

4.1 Facilities and Equipment

4.1.1 Instrumentation Requirements

ETO chambers will employ instrumentation which will enable control of the specified environments within the specified tolerances. Instrumentation calibrations will be in accordance with the following section. Individual requirements for instrumentation necessary to monitor the behavior of the item in test will be specified in the appropriate test specification and will meet the requirements for calibration as defined in the following section.

4.1.2 Instrumentation Calibration

Secondary reference standards will be certified against primary reference standards maintained by the National Bureau of Standards and will be certified accurate to ± 0.5°F or better. The type of standard and frequency of calibration will be approved by the TRW metrology section.

4.1.3 Test Chamber Requirements

4.1.3.1 Test Chamber

The test chamber will be made of materials that are compatible with the decontaminating agent. The material will not be degraded or permeable to the decontaminating agent. Suitable automatic monitoring equipment will be connected to the test chamber to determine ETO concentration and relative humidity, or sampling and determination of ETO and relative humidity will be performed every 3 hours during the first cycle and once each cycle thereafter.

4.1.3.2 Test Chamber Temperature Distribution

Test chambers will be qualified, as defined below, at the specified test temperature rates and extremes. The heating method for the ETO chambers will not produce any localized high temperatures in the heating device which would decompose the ETO mixture either by heat alone or by heat and a catalytic action.

Frequency of Temperature Distribution Measurements. Temperature distribution measurements will be made prior to any qualification or flight acceptance test series.

Location. The minimum number of gas temperature locations to be measured in the empty oven for temperature distribution qualification will be nine. Measurements will be made at eight corners of the volume in the gas stream of a square prism encompassing all regions where test items are to be placed and also at the geometric center of this prism (reference point). Additional measurements will be made at any point within the above volume which may be suspected of having a large temperature variance due to the construction of the particular chamber.

Measurements. The temperature of the reference point will be continuously recorded during chamber qualification test series. A series consists of one reading of each distribution check point. A minimum of three series will be recorded. All readings will be recorded to the nearest $\pm 0.5^{\circ}F$. There will be between 5 and 15 minutes between the start of one series and the start of a successive series.

4.1.3.3. Test Chamber Stabilization and Range

The test chamber will be capable of stabilizing the reference point temperature within the range specified.

4.1.3.4 Vacuum Equipment

The vacuum equipment will be capable of producing the desired vacuum level in 10 minutes or less for chambers up to 2 cubic feet, and in 20 minutes or less for chambers between 2 and 5 cubic feet. The use of larger chambers requires a disposition from the environmental engineer.

4.1.4 Test Performance

Test units will be placed within the volume surveyed for distribution and arranged so that the gas circulates freely around all external surfaces of the unit(s) under test to assure that heat is transferred to the item principally by convection or radiation. Any independent temperature measuring instrument calibrated in accordance with the paragraph on instrumentation calibration may be used to indicate the chamber temperature during the performance of tests. This instrument, however, must be accurate to within $\pm 1.0^{\circ}F$, and the sensor of this instrument must be placed at a point representative of the reference point temperature. Any item in test is not required to operate during the application of the ETO decontamination cycle.

4.1.5 Safety Provisions

Data gathering and analysis instrumentation will be maintained throughout the testing so that any test may be stopped at any time upon command from the test director, environmental requirements engineering, or the test engineer. Fail-safe circuitry controlling the environmental test equipment will be demonstrated to be working properly before any system or assembly is installed within or on any environmental test equipment.

4.2 ETO Procedure

The decontamination procedure for any test on any level of assembly will be as follows:

- Step 1: Place the load within the decontamination chamber and close the chamber door. Verify that the test chamber temperature is in the required range prior to insertion of the load

- Step 2: Introduce the decontaminating agent through a heat exchanger. The nature of the heat exchanger will be so that when the decontaminating agent enters the chamber it will be at a maximum temperature of 86°F. Introduce the decontaminating agent at a rate which will permit reaching an atmospheric concentration of 500 50 mg/liter within 24 minutes. After the stated concentration is reached, circulate the decontaminating agent so that the specified conditions will be met for the constant exposure period as defined. Automatic gas makeup will be used to maintain the specified concentration of decontaminating agent during this period.

- Step 3: After the specified exposure period, apply a vacuum of ~2 inches Hg. During the vacuum cycles, all gases will be vented to the outside atmosphere in a manner that does not constitute a health hazard.

- Step 4: Return the chamber to atmospheric pressure, then flush the chamber with ambient air until two air cycles have been accomplished. In some instances, it may be necessary to repeat the flushing to remove the residual decontaminating agent to a safe level.

- Step 5: Remove the load.

4.3 Data Requirements

All testing will be documented by means of a test results summary form. The summaries will contain at least the following:

a) Tests performed and completion dates. Test specification numbers will be referenced.

b) Signature of the cognizant engineer or his delegate and the signature of the quality assurance representative monitoring the test, when appropriate.

c) The environmental laboratory test report number (a copy of the test report is to be submitted within 30 days after testing to TRW if the testing is not performed at TRW).

d) Number of the failure report and all associated pertinent failure information, including failure analysis and corrective action taken. (The elapsed time between failure and failure analysis resulting from the effects of the ETO environmental will be noted).

e) Hardware serial number, reference designations, and accumulated operating time.

5. NOTES

Gas chromatograph is deemed suitable for determining ethylene oxide concentration and relative humidity percentage.